WIND ENERGY HYBRID SYSTEMS WITH ELCTRIC VEHICLES

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ABSTRACT: This contribution presents general criterion for the dimensioning of hybrid systems with an integration of electric vehicles, which are completely based on renewable energies, including wind energy converter and an equipment for combined heat and power. The electric vehicles are additional consumers, as well as energy storage supporting elements. Because of the different stochastically and dynamical behaviour of the renewable energy supplies in comparison to the consumer, it seems to be unavoidable for such hybrid systems to integrate sufficient energy storage capacities. This circumstance is often used as critical argument to point out a great disadvantage of renewable energy systems. In this case electric vehicles could temporarily serve as (additional) storage capacities, if they are not used for driving. The dimensioning 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.
Keywords: hybrid systems, electric vehicles, modelling

1. INTRODUCTION

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 hybrid systems [1]. Decisive for the construction of a 'renewable' hybrid system is the achievability 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 [3]. 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 [2]. Most important for this is a complex and interconnected view of these problems as one whole undividable unit.

2. HYBRID SYSTEM PRINCIPLES

Important for a successful implementation of such wind energy hybrid systems 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 wind energy and solar insolation, as well as on the energy consumption of for example private households. With respect to the stochastic behaviour of the energy production of a Wind Energy Converter and/or PV-plant, storage batteries for electrical energy are to be involved. But 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. For this reason it may be advantageously to integrate electric vehicles and to regard them concerning their double function; this means as additional (at least necessary in future) consumer as well as helpful supporting storage elements with respect to short-time peak demands of electrical energy [4]. If the electric vehicles are not used for driving, this is the case for most of the time, a defined part of their battery storage capacity could be given free for a bi-directional connection to the hybrid system. As a result, during and after their charging period, the vehicles were able to support the equalisation of the electrical power supply and if necessary to increase the availability. Also positive effects on life-time and costs of batteries may occur, because of the double function and the over-all modified battery-management.

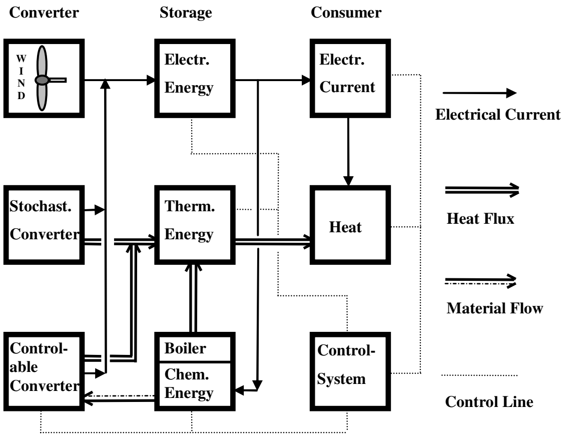

Figure 1: Fundamental Systematic of Hybrid Systems

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 for example:

- *Photovoltaic System*
- *Small Hydro Power Plant* [7]
- *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. Basis for the use of controllable converter is in general also solar energy in stored form like biomass.

Possible *controllable converter* are for example:

- *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. The most important fact 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". This means, the whole system has to guarantee a sufficient variability to fulfil the individual energy requirements from the consumer. For this reason, the additional usually controllable combustion of biomass [5], especially with combined heat and power, is advantageous with respect to a completely renewable energy conversion [6].

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, especially if electrical vehicles are to be integrated. 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. SYSTEMS WITH AN ELECTRIC VEHICLE

In the following, the dimensioning principles for a hybrid system as shown in figure 2 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, with respect to the integration of an electric vehicle.

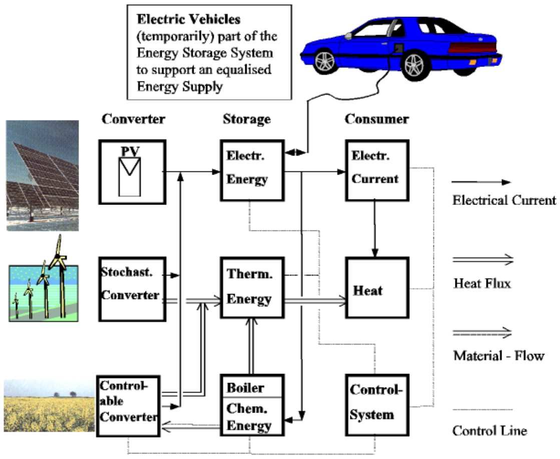

Figure 2: Electric Vehicle as a Part of the Electrical Storage System

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 [1].

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 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.

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

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:

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

In order to integrate ‘one’ electric vehicle into the structure of a hybrid system as described above, first the additional energy demand has to be regarded.

In Germany there exist more than 37 Mio passenger cars, that means nearly 50% of the habitants have a vehicle. Each vehicle drives nearly 13000 km/year with usually one or two passengers. Each person uses a car for averaged 44 km daily [4]. The range of the electric vehicles amounts usually 40 to 80 km. After this, they have to be recharged. Underlying modern experiences with electric vehicles, one can assume an energy demand of 15 kWh / 100 km. This means 6,6 kWh for the above mentioned 44km. Therefore a battery capacity of approximately 10 kWh would be sufficient for nowadays usual electric vehicles. With respect to the battery capacity of 10kWh for the electric and the daily demand of nearly 7 kWh, the additional amount of electrical energy to be produced would be 10kWh/day. Therefore, the formula (1) changes to:

$$\overline{P}_{d,Current+Vehicle} = \left\{ 18,6 + 1,6 \cdot \cos\left(\frac{2\pi}{365} \cdot d \right) \right\},\ d \equiv day\ . \qquad (3)$$

As a consequence, the ration of power to heat doubles approximately. It is also possible to approximate the daily heat-consumption as a cosine-function with sufficient accuracy, similar to (1) in [kWh/d]:

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

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

$$P_{general} = z \cdot P_{average} \qquad \text{with} \qquad (5)$$

$$z = \frac{\text{annual power-consumption}_{\text{house}}}{3146 \text{ kWh}} \qquad (6)$$

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

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

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

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

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

$$a_0 = 6,347505E-01,\quad a_1 = 3,7224486E-03$$
$$a_2 = 1,818859E-04,\quad a_3 = 2,818560E-06$$
$$a_4 = -3,168738E-08\quad a_5 = 9,383729E-11$$
$$a_6 = -8,807513E-14,$$

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.

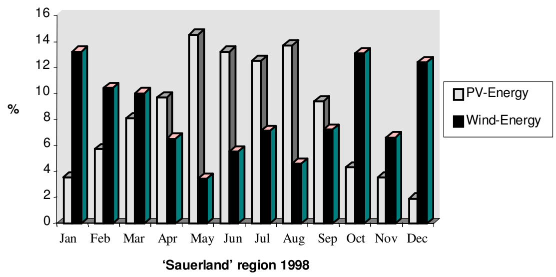

Figure 3: Combination of Wind and PV Energy

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:

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

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

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:

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

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:

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

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:

$$\xi_W \cdot \overline{P}_{d,Wind}(d) + \xi_{PV} \cdot \overline{P}_{d,PV}(d) \geq P_{el,house}(d) + P_{el,vehicle}(d) - \upsilon \cdot P_{heat}(d) \qquad (11)$$

with $P_{el,vehicle} = 10\frac{kWh}{d}$ constant.

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).

Without an electric vehicle 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.

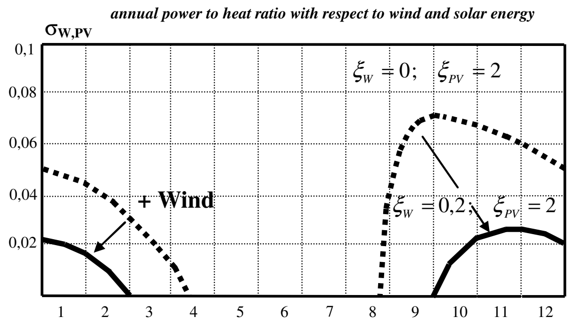

Figure 4: Ratio σ with Wind Energy and a PV-Plant

The PV-plant with $\xi_{PV} = 2$ alone is normally able to supply the private household with electrical energy even with a surplus of 1,8kWh to 3kWh a day in summer times. The additional wind energy converter increases the availability (figure 3) as well as the amount of surplus energy, and it decreases the necessary efficiency of the combined heat and power system in winter.

The decisive season for the storage capacity is the summer, therefore the PV-plant should be increased, but equation (11) has no unique single solution.

For example a hybrid system with $\xi_W = 0{,}2$ and $\xi_{PV} = 3$ would be sufficient, and the amount of surplus is equal to a hybrid system without electric vehicle with $\xi_W = 0{,}0$ and $\xi_{PV} = 2$, but with an increased availability with respect to figure 3. For that reason, apart from the electric vehicle, a battery capacity of 20 kWh in the hybrid system may be sufficient to store the surplus energy of one week. If the supply security is not sufficient, the amount of the wind energy portion could also be increased.

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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