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SOLAR HYDROGEN BASED ENERGY SUPPLY FOR RESIDENTIAL DEVELOPMENT

P. Beckhaus[+], G. Buchholz[*], A. Graw[@], G. Krost[+] and J. Matics[+]

[*]H_2 Energie AG, An der Eickesmühle 35, D-41238 Mönchengladbach, Germany
[@]Planungsbüro Graw (Engineering), Senator-Wagner-Weg 4, D-49088 Osnabrück, Germany
[+]Gerhard Mercator University, Faculty 5-EAN, Bismarckstrasse 81, D-47057 Duisburg, Germany

ABSTRACT

The worldwide energy situation forces to investigate alternative concepts of energy supply, preferentially such ones involving renewable sources and – in consequence – energy storage. An innovative approach of a detached residential development electricity / heat supply is presented which is primarily based on photovoltaic, wind generation and hydrogen energy storage; first simulative results confirm the principal feasibility and motivated for a pilot implementation.

INTRODUCTION

Increasing energy demand worldwide, limitation of fossil energy resources as well as threatening climate changes can only be counteracted by the use of renewable energy sources. However, due to the stochastic energy harvest effective and flexible energy storage is required. *Hydrogen* is well-known as an interesting medium for energy storage. The idea followed in this paper is to use an electrolyser / fuel cell hydrogen path for the energy storage purposes in the frame of an self-sufficient electricity / heat supply of a detached residential development. The principal plant configuration is shown in Figure 1.

The project being now under consideration for pilot realization refers to a planned housing estate with 80 apartments, supplied by both 300 kW_{peak} photovoltaic and 350 kW wind generation, the latter connected via the public mains in this case. The hydrogen storage path is intended to consist of a 30 Nm^3/h elektrolyser, a 70 m^3 hydrogen tank (300 bar) and 150 kW fuel cell, or hydrogen gas motor driven generator alternatively, in each case as combined heat generation. The local distribution comprises the low voltage cable network, the thermal system with heat pumps and heat tank storages, as well as the data network for measurement, metering and control.

For such an application a powerful energy management is required, taking into account actual process information as well as prospective data such as consumption profiles and expected energy harvest. An expert system has proven as flexible and transparent solution for such comprehensive task which was experienced from multiple applications. A specific implementation will be developed and applied for the residential development supply reported here.

First step in project realization is a comprehensive and iterative simulation. The detailed plant design will be calculated depending upon exact data of applied components, the consumption and construction data of houses and apartments, geographic details and other restrictions; several alternatives in the arrangement (e.g. central, hub based or house internal heat storage, hydrogen gas motor vs. fuel cell) have to be investigated.

This investigation is presently being performed by use of a flexible simulation tool which allows to model arbitrary configurations of detached electric-thermal supply systems with high grade of detail and time resolution; the simulation is also used for the verification of the plant management system mentioned above.

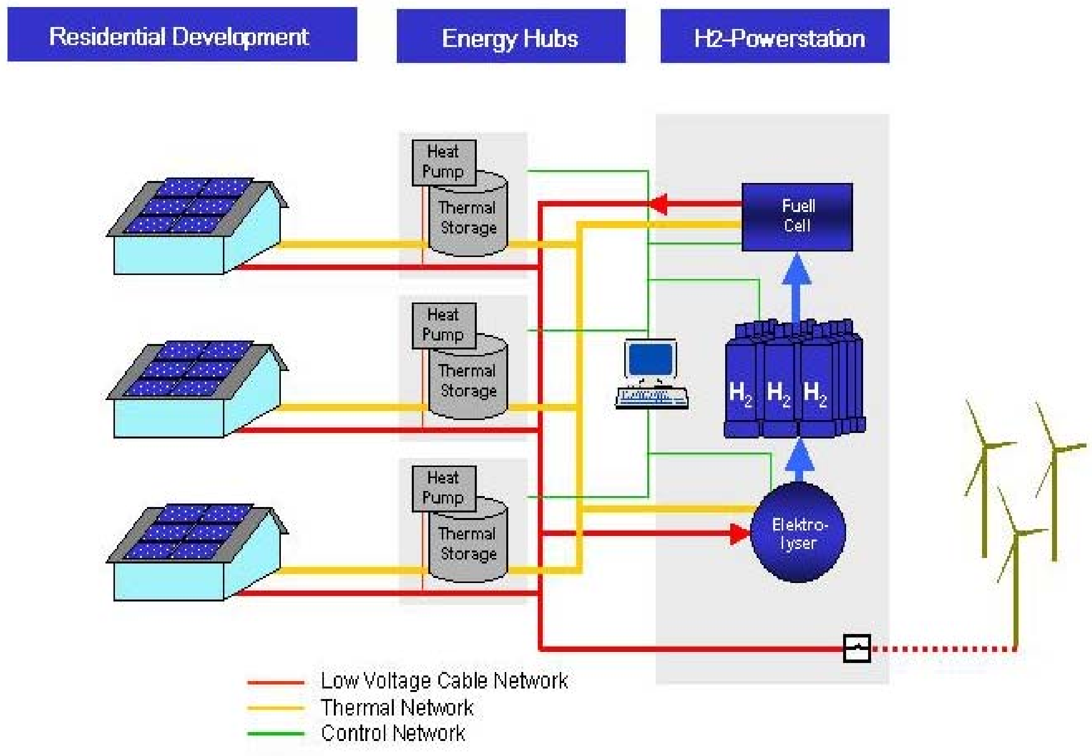

Figure 1: Solar hydrogen residential supply

SAMPLE STUDY

In anticipation before the acquisition of the concrete project mentioned above, the principal feasibility of a solar-hydrogen based residential supply was investigated in the frame of a university study considering a fictitious ensemble of 75 low-energy houses with an estimated total electric demand of approximately 180 MWh/year and a thermal demand of about 465 MWh/year which are reasonable values for modern low-energy construction method and a location in the western part of Germany. This study gave a principal insight into a possible structure of such kind of solar-hydrogen based supply as well as the complexity of the operational conditions. The concept adopted provides 5 energy hubs (de-central energy stations) , each supplying an ensemble of 15 houses, see Figure 2.

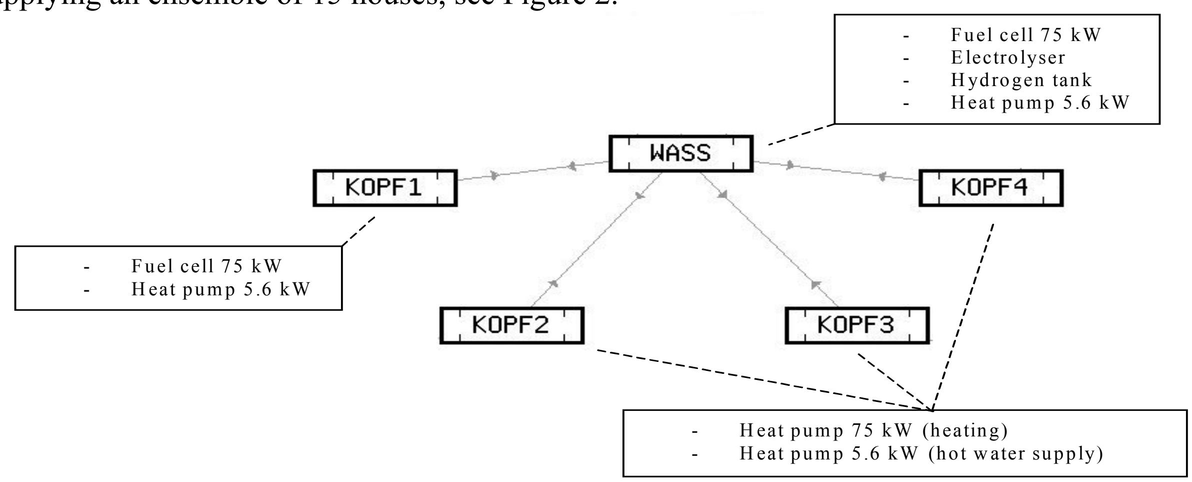

Figure 2: Topological system configuration with energy hubs

The particular hubs comprise each

- an **electric** 230 V AC sub-system, connecting the photovoltaic panels (4.8 kW_{peak} per house, i.e. 72 kW_{peak} per hub) via DC/AC converters, as well as load feeders for residential electric supply and auxiliary devices such as heat pumps, Figure 3, left side; the 5 hubs are electrically interconnected via low voltage cables, see Figure 2.

- a **thermal** sub-system (see Figure 3, right side), consisting of load feeders for room heating and hot water supply, as well as a heat storage tank; thermal sources are:
  - an electrically driven 5.6 kW heat pump for hot water supply (summer and winter operation);
  - for room heating, three of the hubs are equipped with another heat pump of 75 kW; in two of the hubs the waste heat of a 75 kW_{el} fuel cell is used instead of this second heat pump, see Figure 2.

During winter time these fuel cells provide additional electric sources; they are operated on hydrogen gas, which is produced during summer times with considerable photovoltaic electric energy surplus by an electrolyser. This electrolyser is installed together with a hydrogen storage in one of the hubs housing the fuel cells, see Figure 2.

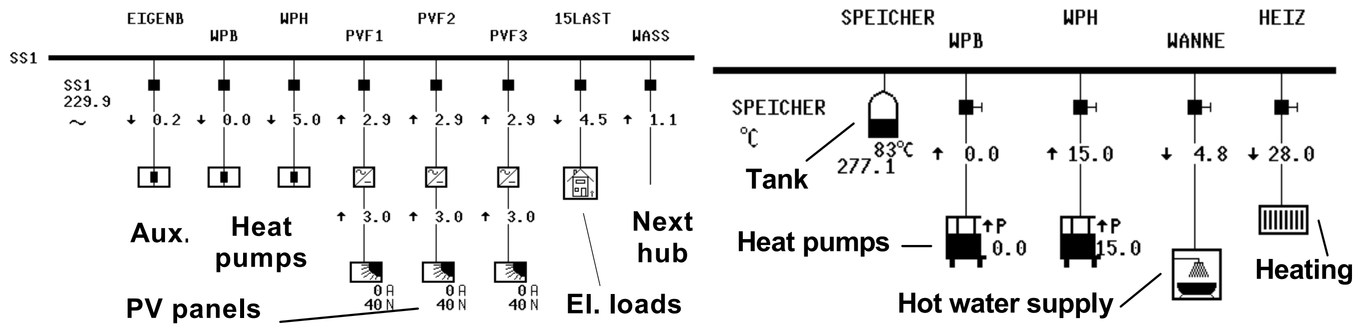

Figure 3: Electric and thermal circuitries of energy hubs

Even if the operational concept intends to reach energetic independence, the electric interconnection with the public mains in one of the hubs is used for energy buffering and for emergency; under present market conditions in Germany, the subsidized renewable generation earnings in connection with limited peak load power are expected to be economically reasonable compared with an accumulator storage; in rural areas – eventually without any existing public mains – a fully detached system would be reasonable.

The control strategy for the described plant has to meet various goals:

- The primary one is the uninterrupted supply of the households with thermal energy for both hot water and heating since there is no backup source.

- The electrical energy supply is backed up by the public mains connection; but in order to fulfill the criterion of energetic independence, the energy exchange with the grid should be zero on average, thus having the public mains as an energy buffer, and the exchange power shouldn't exceed a maximum amount.

- The storage commitment (heat and hydrogen) has to consider both short and long term perspectives.

Therefore, in summer times the heat pumps for hot water supply should be working during hours of high solar input and the heat should be stored. In order to keep up the electric load power margin, during winter times the energy management has to carefully coordinate the operation of water and heating heat pumps; during times of low irradiation the working hours of heat pumps and fuel cells also have to be matched.

Special regard has to be paid to the mutual interdependence between the electric and thermal circuits, given by the fuel cells being both electric and thermal sources, and the heat pumps being thermal sources and electric sinks.

All this requires a multi-level control which can be realized for the simulative studies by means of the energy management expert system mentioned above, dealing with

- prognostic load forecasts for both thermal and electrical loads,
- estimation of expected PV power generation and energy harvest;
- heat-storage management.

The first approach of this control was coupled with the simulation of the entire energy system for further optimization of the plant parameters as well as for fine tuning of the control. Some results of the system behavior procured on a sample day in February are shown in Figure 4.

The left part is dedicated to the *electric* powers of solar feed, fuel cells, heat pumps and public mains exchange. The total electric load (not displayed here) of the 75 houses was assumed to be varying between 17 and 27 kW during the considered period of time. The right part of Figure 4 shows the total *thermal* consumption and the thermal feed provided by heat pumps and fuel cells.

The thermal demand – dominated by heating – as preferential matter for orientation of the energy management is close to zero at night time (low energy houses) and increases in the early morning for heating of the apartments; later in the day, due to sunshine (see electric solar input curve) this demand is lowered, and after sunset it increases again until the night heating-temperature reduction applies. This global demand is generally covered by the thermal feed – see curves in Figure 4 –, whereby the deviations between both shapes are buffered by the heat tank storage.

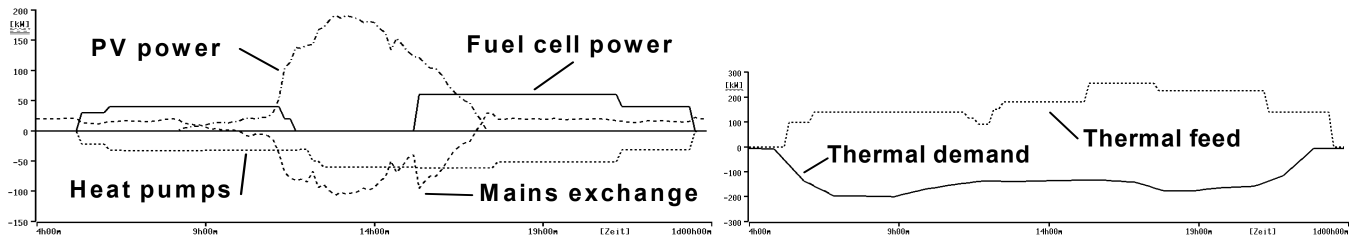

Figure 4: Electric and thermal powers during sample day

Closer analysis shows that the three hubs equipped with heat pumps are covering the heat requirements on demand. The two fuel cell powered hubs are assumed to be controlled in that way that both the local thermal demand as well as the global electric power consumed by the heat pumps in the other three hubs are covered. This is actually achieved by operation of one of the fuel cells in the morning, and the other one in the afternoon and evening – see left part of Figure 4.

Regarding the *electric* behavior, the operation of the fuel cells leads to low power import from the public mains. The upcoming considerable solar generation before noon in combination with the decreasing thermal demand result in stepwise shut down of the fuel cell, and to an electric power export to the public mains. In order to exploit the solar energy availability more efficiently, during the early afternoon the heat pumps are increased in power, thus charging the thermal storages. In connection with decreasing solar input in the later afternoon, the other fuel cell is operated until minimal thermal demand is reached late in the evening.

An analysis of the energy balance on that sample day proved that

- the total thermal consumption of the 75 houses of approx. 2.7 MWh was over-compensated by thermal input of 3.2 MWh, thus charging the water tank storages with the surplus of 500 kWh;
- the electric import of 291 kWh from the public mains was over-compensated as well by an export of 436 kWh, leading to a surplus of 145 kWh.

This energy harvest provides flexibility with regard to the control during the following days even when worse irradiation conditions should occur. The limited electric exchange power (max. 30 kW import and 100 kW export respectively for the entire residential development, see Figure 4) moderates the cost for this connection. Alternatively, an electric accumulator storage could be investigated for achievement of full energetic independence. Also the additional inclusion of wind generation will be considered as further variation.

As mentioned before, the scenario shown above is taken from the results of very first studies on such kind of energy system; but they are reasonable and transparent and prove that the solar-hydrogen based concept is suitable as independent energy supply even in areas with moderate solar irradiation.

CONCLUSION AND PERSPECTIVES

An innovative concept for autonomous residential electricity / heat supply based on hydrogen energy storage was presented. Primary simulative studies were performed on a fictitious sample system in order to derive possible design of both plant configuration as well as operative management structures. These studies proved the principal energetic feasibility of the adopted approach and motivated to take up a first pilot realization which – of course – has to be largely subsidized. On the other hand, the concept pursued significantly contributes to provide a long term perspective for the dispersed use of fuel cells purely based on renewable hydrogen production; this is in distinct contrast with the solutions presently propagated where hydrogen reformed from natural gas is restricted by the existing fossil reserves.

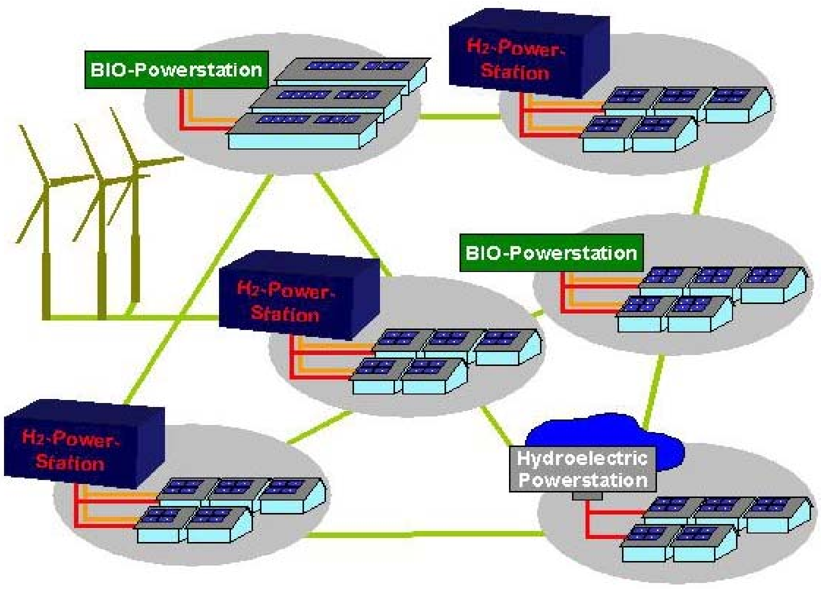

Figure 5: Renewable energy supply in electrically connected regions

This further means that the vision of regenerative energy supply that does not depend upon any conventional power stations can be realized in some areas; especially for regions with high solar irradiation where firm energy systems are not yet existing, the energetic autonomy contains a high potential for such useful implementation. On the other hand, in regions with existing electrical systems H2POWERSTATIONS complement the regenerative energy mix of wind, photovoltaic, biomass and hydro in order to provide autonomous energy systems which can be drawn upon at any time (Figure 5).

Of course, one of the major questions is the economic efficiency. The initially expensive technology can be used in more economic way if it can be combined with additional benefits for the customer:

- As an island system set up in areas that are currently not electrically connected it guarantees the availability of energy supply while preventing the need for the procurement and transportation of fossil fuels or the expansion of energy networks.
- As a peak load system combined with other regenerative energy systems it makes possible a reliable energy mix consisting exclusively of regenerative sources – hardly conceivable today; in this case the economic yardstick is the *peak energy price*.