WINDMILL – ELECTROLYSER SYSTEM FOR HYDROGEN PRODUCTION AT STRALSUND

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1. PROJECT GOALS

A Multi-component Laboratory for Integrated Energy Systems has been established at Fachhochschule Stralsund – University of Applied Sciences. This Laboratory will be used to train engineering students and to conduct research on renewable energy sources and hydrogen technology. Electrical and mechanical engineering students can use the facility for practical work in this field. Additionally, since 1997, a one-term international course on renewable energy has been offered, in which students from Spain, Poland, Latvia, Estonia, Russia and Argentina have taken part. Furthermore, every spring for the last eight years, a ten-day course on renewable energy sources and hydrogen technology has been offered, with students from Norway, Sweden, Great Britain, and Eastern Europe participating. The two latter courses were taught in English.

One feature of this laboratory is a windmill–electrolyser system for carbon dioxide-free hydrogen production. This system was designed to show that the intermittent operation of an electrolyser, with a changing power input due to a changing wind speed, is possible. A process control system allows collection of data that can be used in simulation calculations. The demonstration and testing of this windmill-electrolyser system provides valuable experience in the operation and design of such integrated systems. The system is also one step towards an island solution for a hydrogen-based energy supply.

2. GENERAL DESCRIPTION OF THE PROJECT

The Multi-component Laboratory includes a variety of energy conversion devices that can convert renewable sources of energy, such as wind and solar energy, to thermal or electrical energy. These are listed in the left hand column of Figure 1. The components can be integrated into the thermal or electrical network, or investigated individually as an island solution. The conversion of energy from one form into another is color-coded as follows: red for solar energy or heat, green for wind energy or biodiesel, blue for electricity, and yellow for hydrogen. The middle column of Figure 1 lists the energy converters and the right hand column lists the devices for energy storage and energy output. All in all, Figure 1 shows the multiple possibilities for energy conversion in the laboratory. The aim of this system is to offer the opportunity to use each piece of equipment as a single device for practical work.

The following partners are working together with the Fachhochschule Stralsund – University of Applied Sciences in this project:

ELWATEC GmbH, GRIMMA	Electrolyser
SPARTEC, GÜSTROW	Photovoltaic Installation
VENTIS ENERGY AG, BRAUNSCHWEIG	Windmill
ELTA GmbH, ROSTOCK	Cogeneration Plant
ESN, GREIFSWALD	Electrolyser Station
TAB, BERLIN	Gas Mixture Installation
GePro mbH, STRALSUND	Measurement Equipment.

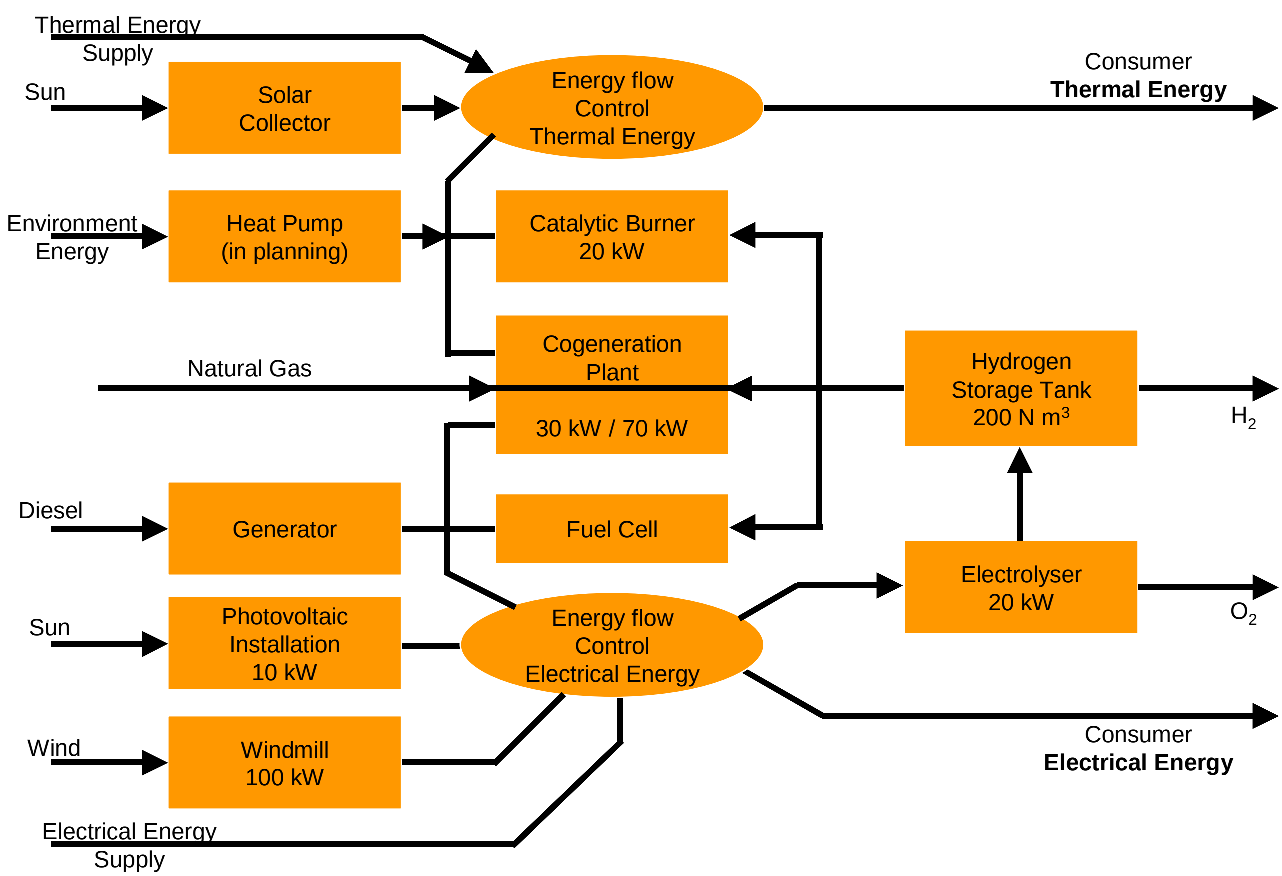

Figure 1: Components and their integration in the Multi-component Laboratory

3. DESCRIPTION OF COMPONENTS

3.1 The Windmill and the Photovoltaic Installation

Figure 2 shows the windmill and the photovoltaic installation. The windmill has a rotor diameter of 20 m and a hub height of 30 m. The windmill rotor speed is 40 or 60 rpm. A gearbox, which is equipped with an active hydraulic pitch-control system and controlled by a microcomputer, increases the rotor speed to either 1,000 or 1,500 rpm, as required for the wind generator. The nominal power output of the wind generator is 100 kW. However, depending on the wind speed, the two-speed asynchronous generator can be operated at either 1,000 or 1,500 rpm, producing 20 kW or 100 kW of electricity, respectively. The control system saturates the average power output to 100 kW if the wind speed is higher than 12 m/s.

Figure 2: Photovoltaic installation and windmill

The generator is directly coupled to the mains supply, which means that a variation in wind speed leads to a fluctuation in the actual current and power output. The pitch control system works too slowly to smooth the power output. The modification of a constant speed windmill to a variable speed windmill has been reported in [1]. It has been shown in that paper that power smoothing of a wind turbine is desirable, but is not necessary in terms of the system stability of the electrolyser. In the Multi-component Laboratory, both systems are coupled to the mains supply and therefore load fluctuations do not have a direct influence on the electrolyser. However, in the case of island grids, a special design of power supply is necessary.

The photovoltaic field consists of 3 different module types; the technical specifications for each type are summarized in Table 1. The peak power output amounts to 9.6 kWp. Each string is connected to one inverter with a rated power output of 1,500 Wp. Additional equipment has been installed to measure module temperature, insulation, string current, and voltage. All data are collected with the Windows Control Centre (WINCC).

Table 1: Technical data of photovoltaic installation

String	Modules per String	Type of silicon	Peak power	Sum
			Wp	kWp
1 / 2	13	mono-crystalline	110	1.43
3 / 4	26	mono-crystalline	55	1.43
5 / 6	13	poly-crystalline	90	1.17
7	28	amorphous	60	1.54

3.2 Electrolyser and Storage Tank

The windmill and electrolyser have been operated in the Multi-component Laboratory at University of Applied Sciences Stralsund for several years. This 20-kW alkaline pressure electrolyser was developed and is maintained by ELWATEC GmbH Grimma, now Hydrogen Systems GmbH. Unlike other electrolysis systems operating at atmospheric pressure, this system can deliver hydrogen at up to 25 bars without using a compressor. The system comprises 40 cells characterized by a very compact bipolar design. In fact, the electrolyser is so compact that it can easily be made portable by fitting it into a suitable container. The electrolyser is shown in Figure 3, and the main technical data are presented in Table 2. A detailed description of its operational behaviour is given in [2].

Figure 3: 20 kW pressurized electrolyser

Table 2: Technical data of the electrolyser

Hydrogen capacity	Nm^3/h	4
Oxygen capacity	Nm^3/h	2
Gas purity hydrogen	%	>99.7
Energy consumption	kWh/h	20
Operating pressure	bars	25
Number of cells		40
Operating temperature	ºC	ca. 60
Weight	kg	450
Geometrical dimensions:		
...of electrolyser	mm*mm*mm	700*1150*1890
...of transformer	mm*mm*mm	800* 400* 700
...of switchboard	mm*mm*mm	800* 300*1000

The hydrogen storage tank has a geometrical volume of 8 m^3. However, because the system works without a compressor, the tank is only used to the maximum pressure of the electrolyser. Under 25 bars, the tank is filled within 50 hours and contains 200 Nm^3 hydrogen. A two-stage compressor with an output pressure of 300 bars is available for filling up tanks or bottles.

The static and dynamic behavior of the electrolyser was investigated. Figure 4 shows the hydrogen production curve as a function of the current. The efficiency of the stack reaches about 80% on a HHV basis. The electrolyser can be controlled based on the power output of the windmill. The dynamic behavior for 90% load changes and the controlled operating regime are plotted in Figures 5 and 6, respectively. The plots show that this type of intermittent operation is possible.

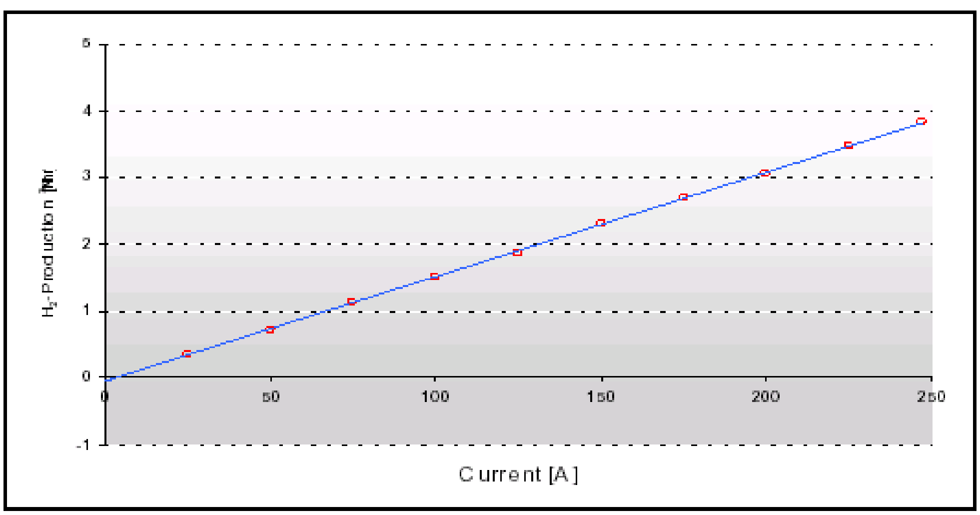

Figure 4: Hydrogen production

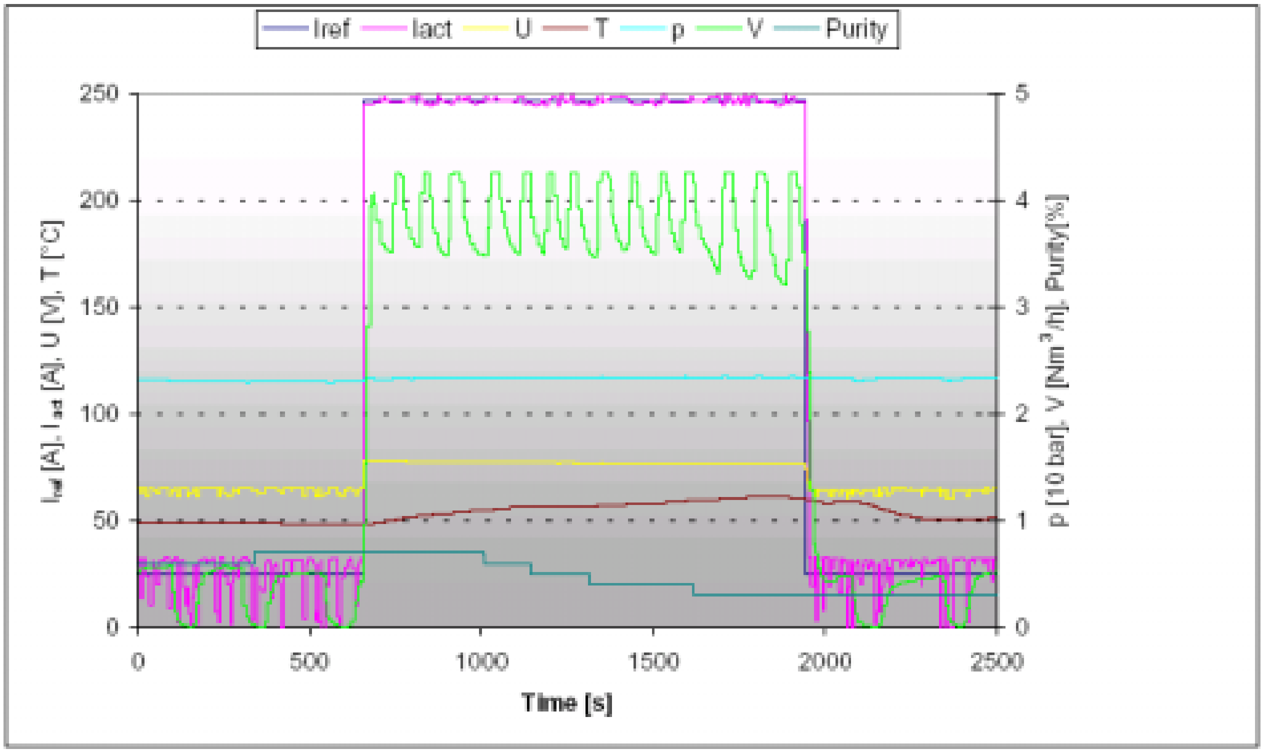

Figure 5: Load change of 90%

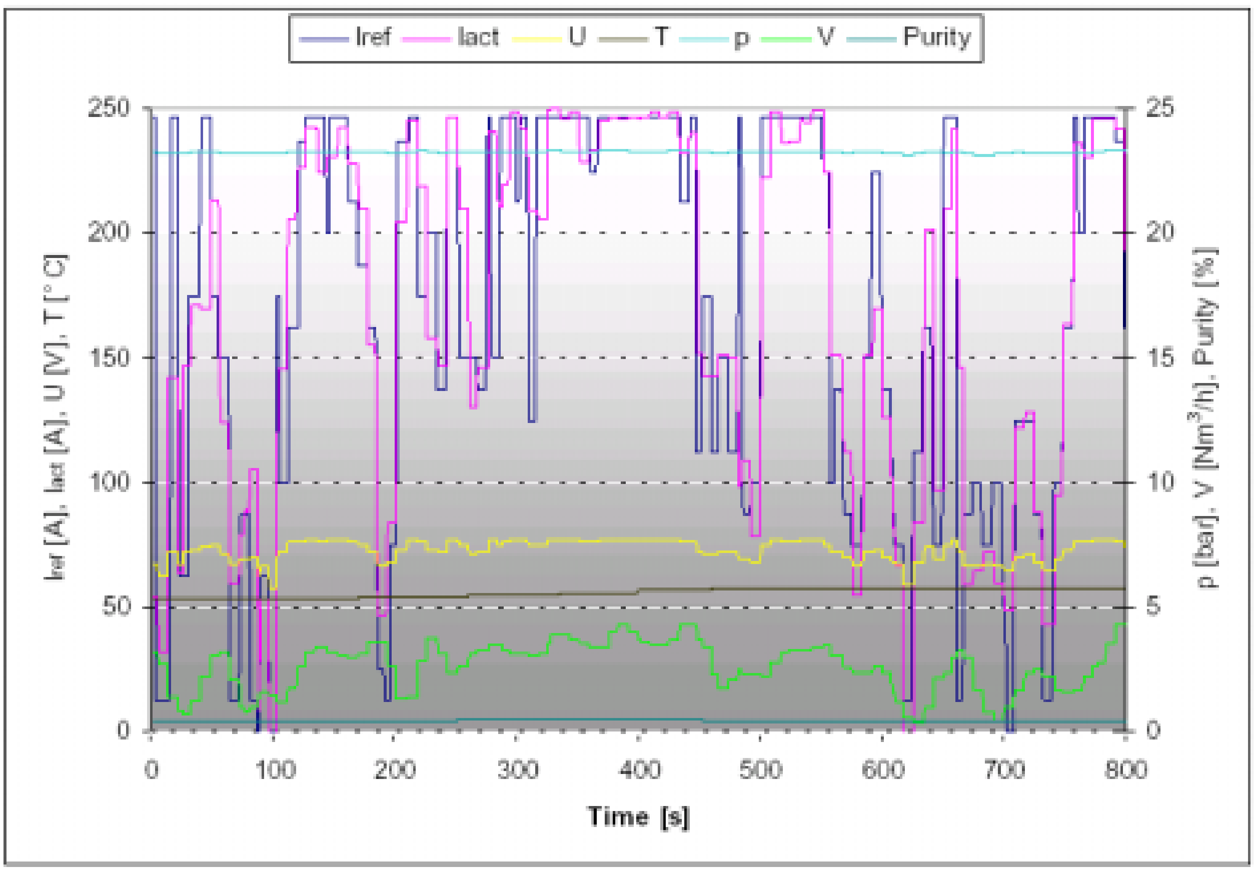

Figure 6: Windmill controlled electrolyser

3.3 Fuel Cells

A test bed for measuring the operating parameters of a PEM fuel cell has been installed in the Multi-component Laboratory [3]. This test bed was provided by the Center for Solar Energy and Hydrogen Research Baden-Wuerttemberg (ZSW; Ulm, Germany). Tests were conducted to determine:

- Voltage versus current curve
- Power output curve
- Fuel cell efficiency
- Temperature behavior of the fuel cell
- and the dynamic behavior according to load changes.

Table 3: Power output of the PEM fuel cell at different temperature levels

Temperature	Current	Voltage	Power
ºC	A	V	W
51.4	28.6	11.7	334.6
53.1	29.4	12.0	352.8
54.0	29.7	12.2	362.3
54.6	30.8	12.0	369.6
56.6	29.8	12.2	363.6

The temperature behavior of the PEM fuel cell is shown in shown in Figure 7 and Table 3. The highest power output of 370 W was achieved at about 55°C, which is the suggested operating temperature of this fuel cell. A higher temperature should allow a higher power output, but only if the humidification of the gas could be better controlled. Humidification of the membrane is one of the main problems in this type of fuel cell.

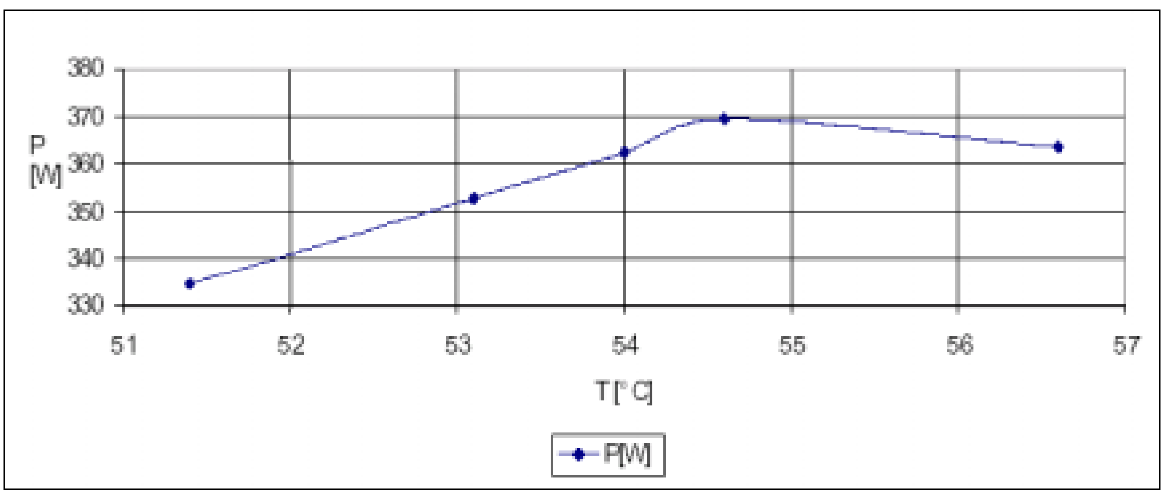

Figure 7: Temperature behavior of the PEM Fuel Cell

Figure 8 shows the current versus voltage curves of the fuel cell. These curves are similar to those presented in the literature. The first part of these curves indicates activation polarization, the second part indicates ohmic losses, and the third part indicates a concentration polarization. The dependence of the power output on the voltage is presented in Figure 9. The maximum power point of the fuel is reached at a voltage of 11 V. This information is important for the inverter design. The efficiency of the fuel cell is shown in Figure 10). While there are different definitions of the efficiency of a fuel cell, one practical way to express the fuel cell efficiency is by simply considering the ratio of electrical power output to fuel input. The lower heating value H_u = 10,800 J/l was used in the calculations of η_{FC}.

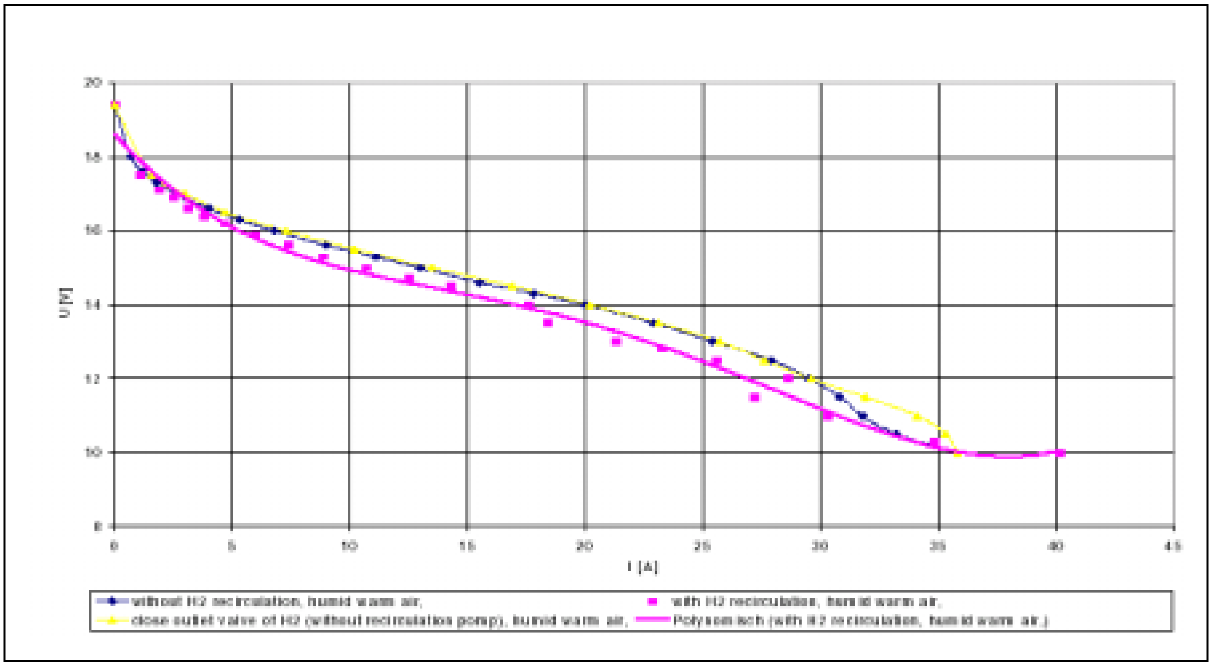

Figure 8: Voltage/current diagram of the PEM Fuel Cell

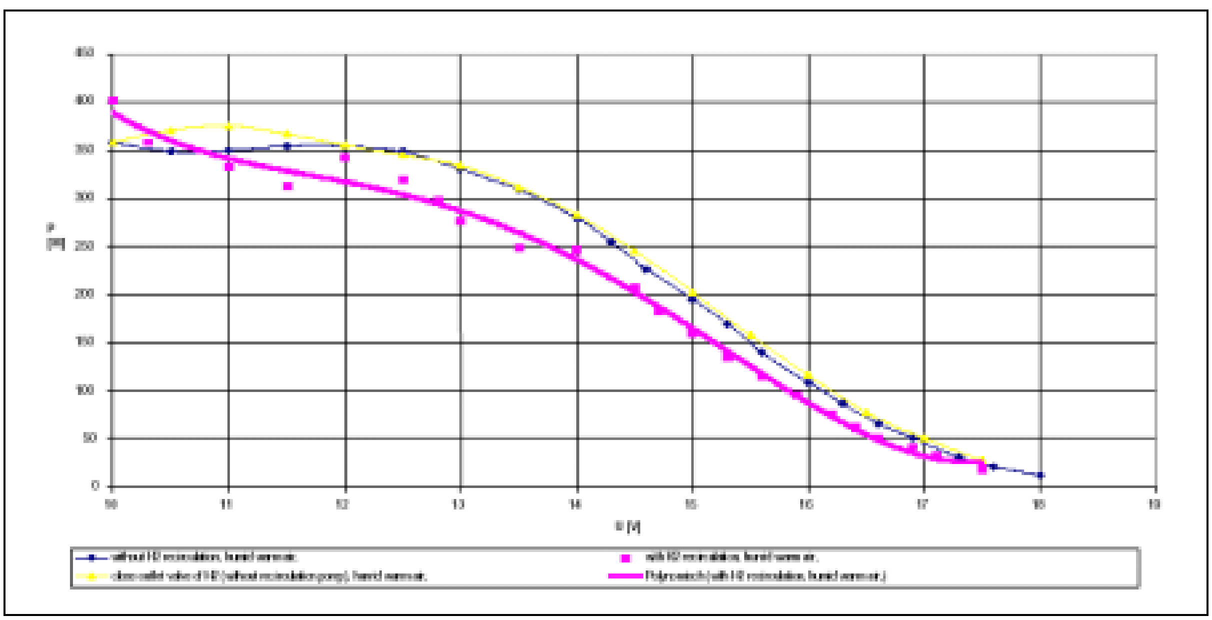

Figure 9: Power versus voltage

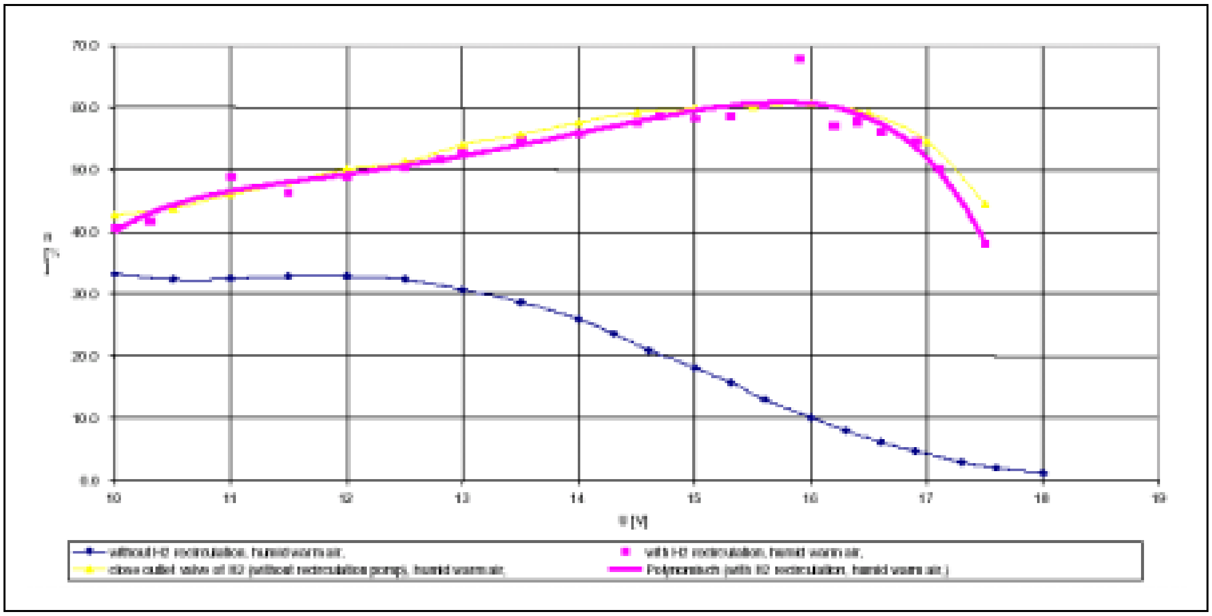

Figure 10: Fuel cell efficiency depending on the voltage

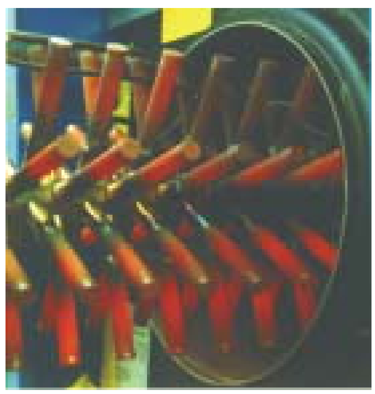

Figure 11: Catalytic burner

3.4 Catalytic Burners

Hydrogen can be directly converted to thermal energy by a catalytic burner. A catalytic burner with a thermal power output of 21 kW has been developed by the Fraunhofer Institute for Solar Energy Systems (Freiburg, Germany). The burner consists of a gas distribution system and 64 cylindrical fuel elements. Figure 11 shows the catalytic burner in a standard Buderus device, and its main operational data are given in Table 4.

The main advantages of the catalytic hydrogen burner are:

- High safety standard
- Low NO_x emissions
- Simple and sturdy construction.

A detailed account of the properties and the experimental data obtained with this burner are given in reference [4].

Table 4: Main operational data of catalytic burner

Thermal power output	kW	21
Burner surface temperature	ºC	< 800
Heat flux density	W/cm^2	10
Hydrogen requirement	Sm^3/h	7.2
Hydrogen system pressure	mbar	20
No_x-emissions	ppm	.9 – 1.4

In a separate project, the same type of radiating cylindrical elements has been used to construct a non-stationary hydrogen cooker (2 kW). Because of some advantages over other hydrogen storage techniques, a portable hydride storage system has been used. So far, a satisfactory combination of geometrical and thermal properties that results in a favorable design for this system has not been found[5].

3.5 Others

To increase the opportunities for students to gain experience with integrated energy systems, additional components have been included in the Multi-component Laboratory. A cogeneration plant with a power output of 30 kW_{el} and 70 kW_{therm} has been installed. While it is normally fed by natural gas, the investigation of hydrogen – natural gas mixtures is also possible. A photovoltaic simulator has also been installed. It allows the simulation of solar fields of up to 50 kW. A diesel generator is available to establish an isolated network.

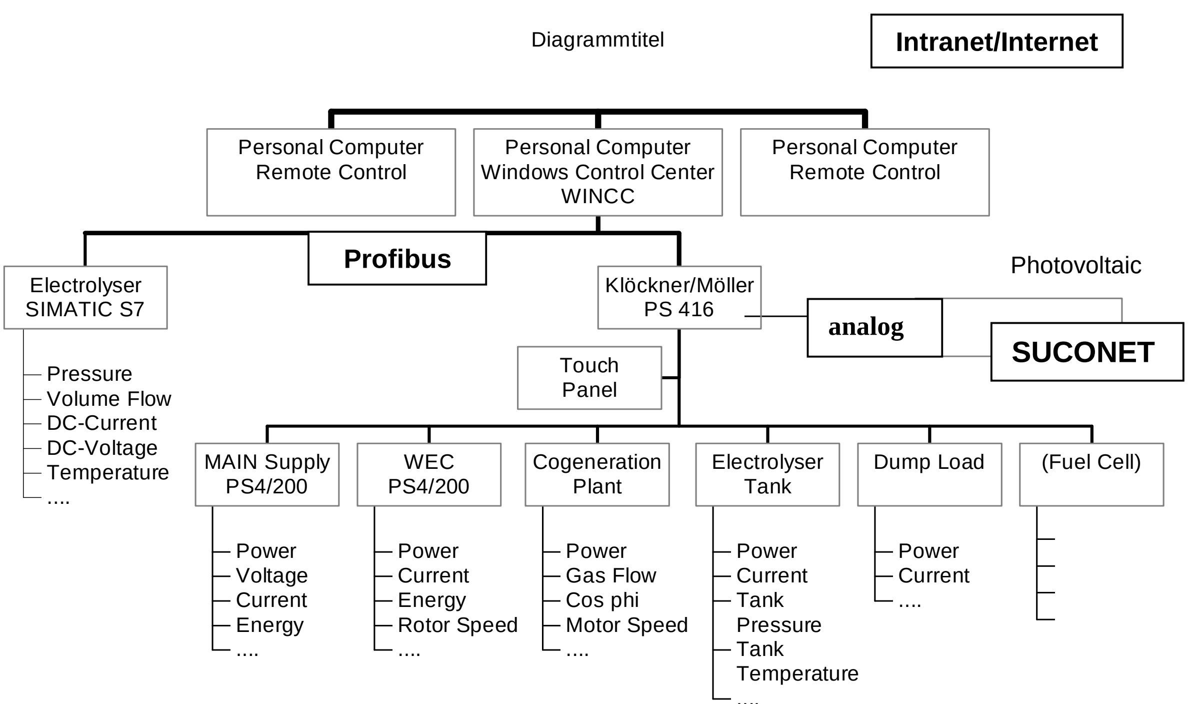

Figure 12: Structure of the data collection system

4. INTEGRATION OF COMPONENTS

All components are grid connected. They can be operated separately. The reason for this design is the laboratory aspect of the system, which allows students to evaluate and independently test individual components.

5. DATA ACQUISITION

The configuration of the data measurement and control system is shown in Figure 12. The data are measured by different sensors. Each system is controlled by its own PLC. The SUCONET connects the six PS 4/200 with the central PS 416 and the touch panel. Remote control of the electrolyser from the touch panel is possible via the profibus. Process visualization and central data collection were done by a central personal computer running the Windows Control Centre (WINCC). This central PC is connected via the profibus to the PLCs and via the Intranet/Internet to other PCs. In that way, remote control and process visualization is possible from any Internet-connected PC.

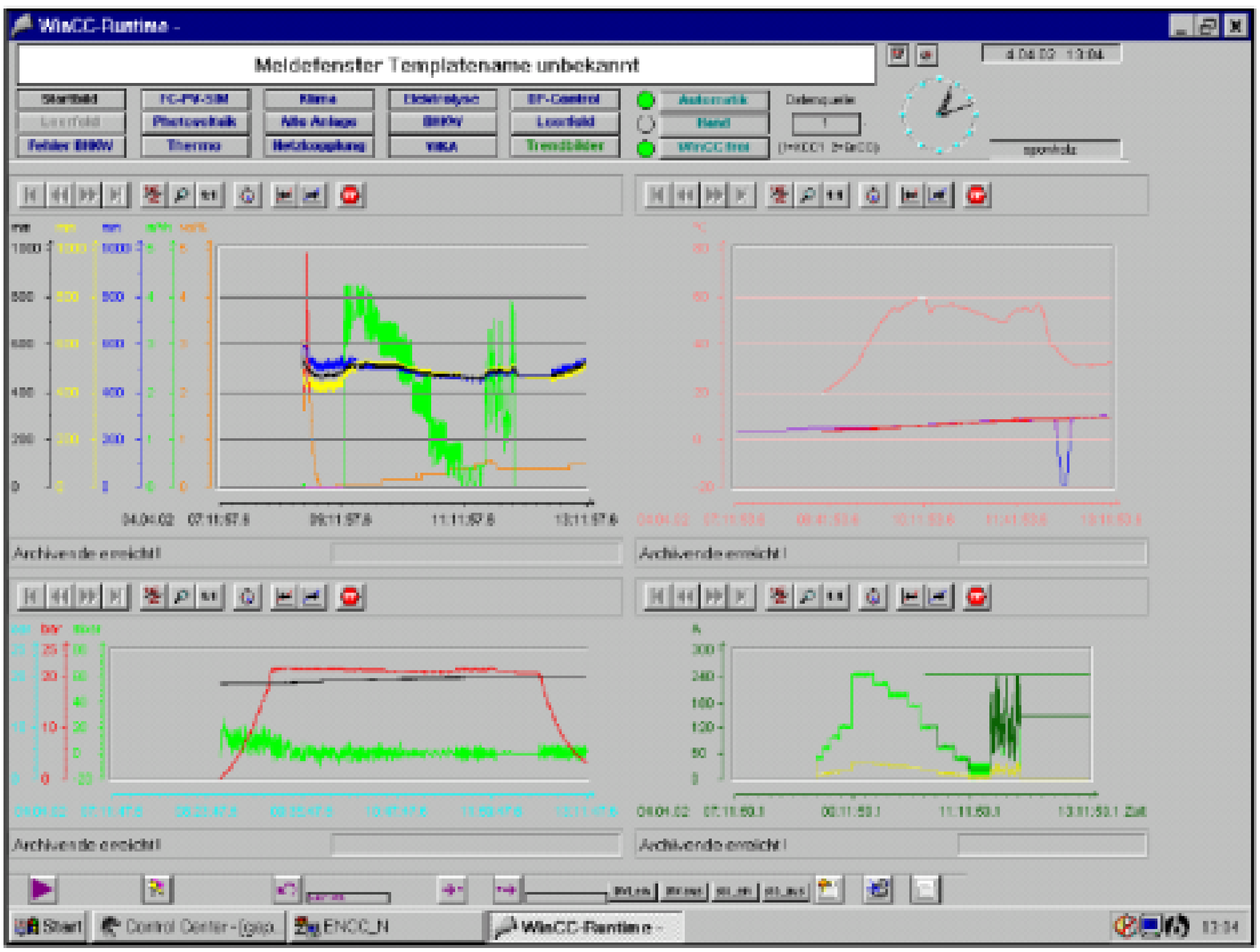

Figure 13. Data collection of the electrolyser

The data can be collected in different archives. Data collected during an experiment can be exported into ASCII-files for further data processing and simulations. As an example, an electrolyser screen is shown in Figure 13. The process of complete data collection beginning with the electrolyser start, turning over to partial load operation, and finally, to windmill-controlled operation.

6. CONCLUSIONS AND FUTURE PLANS

During the past seven years all participating partners have gained valuable experience in the operation of the windmill-electrolyser system:

- The modular design of the system allows each piece of equipment to be used for separate experiments.
- Another advantage of the design is that a breakdown of a single component does not imply a breakdown of the complete system.
- The electrolyser can be successfully operated with intermittent electrical loads. A special design for real island solutions is necessary. A dump load should be used for grid stabilization.
- The system is a good basis for training and data collection.

The main purpose of the Multi-component Laboratory for Integrated Energy Systems is to train students in energy and environmental engineering and hydrogen technology. Staff will also carry out applied research work, development, support, and evaluation of project ideas and projects.

7. REFERENCES

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8. CONTACT INFORMATION

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