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Solar-hydrogen Based Autonomous Electric Power System in Operation

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Abstract

This study presents a solar-hydrogen based autonomous electric power system installed at the University of Applied Sciences Ansbach; and its operational characteristic. The system is comprised of photovoltaic modules, inverters, an electrolyzer, a hydrogen energy storage and a fuel cell. Such off-grid power supply stations which are based on sustainable energy sources can reduce carbon dioxide emissions and can operate during darkness. The aim of this project is the reduction of costs of the system in order to get a competitive autonomous electric power supply. The energy balance and the conclusion are presented as well as a look into the future.

1 Introduction

As the proportion of renewable energies grows, energy storage and intelligent energy management are becoming increasingly important [1, 2]. The irregular energy output and the large number of decentralized regenerative power plants contribute to this development. Owing to two fundamental trends in Germany – the declining proportion of fossil and nuclear energy sources and the increasing share of renewable energy – the demand for energy storage capacity will rise within the next decades [3]. Studies reveal that in regions without connection to public energy grids, small energy grids are sensible and practicable [4]. In this connection the storage of fluctuating energy is particularly important [5].

With its high specific storage density, high degree of environmental compatibility and storage capacity without loss, hydrogen is a favourable energy carrier. Surplus energy from fluctuating energy sources can be converted into storable hydrogen (6). This would ensure a maximum degree of independence from fossil resources, from public grids as well as wind and irradiation conditions. In the long run hydrogen will continue to gain in importance in the energy industry [7].

The off-grid power supply system at the University of Applied Sciences in Ansbach consists of a photovoltaic array, inverters, an electrolyzer, batteries, a hydrogen tank and a fuel cell. This system forms an island grid which supplies conventional electrical consumers with energy at any time independently from the public grid. Firstly the energy demand is covered by the PV array; the batteries are charged by surplus energy and hydrogen is produced for long-term storage. At times of low performance of the PV array hydrogen is reconverted in electrical power. The long-term hydrogen-based storage system permits the use of smaller solar module surfaces and is a reliable way to provide supply security during periods of low renewable energy output. In this connection, supply security means that at any given time the entire power demand must be covered by the storage system as the PV array would not be generating any power. Thanks to its modularity, individual components of the system can be scaled as needed. In this way varying demands concerning performance, storage capacity and costs can be met. Additional generators and loads can easily be connected to the island grid based on alternating current. The objective of the island grid at the University of Ansbach is to provide practical evidence for a sustainable and secure power supply based on conventional components and renewable energies.

2 Experimental System

The autonomous island grid consists of conventional components (see figure 1).

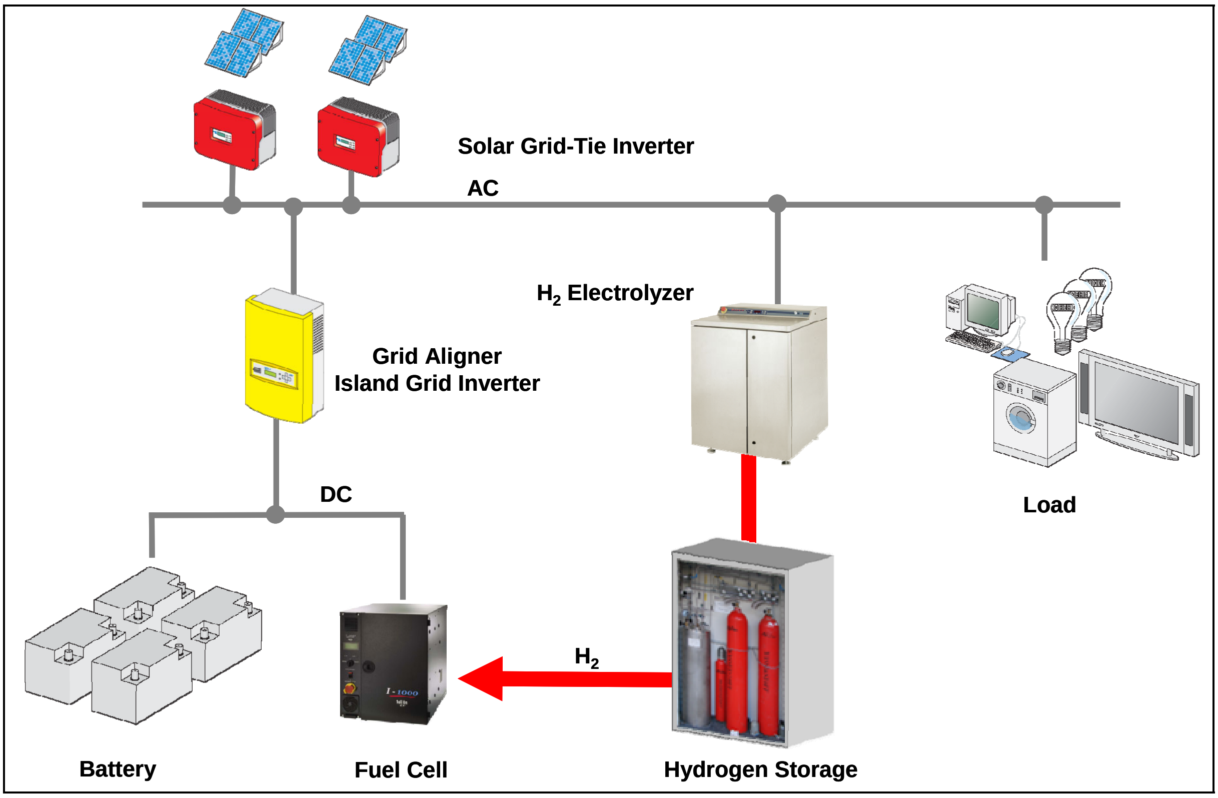

Figure 1: Solar-hydrogen based autonomous electric power system at the University of Applied Sciences Ansbach.

Electrical consumers are supplied by the PV system installed on the roof of the university.

Inverters convert direct current from the modules into alternative current for the island grid. A grid aligner and an energy storage system ensure stability of the 230-VAC island grid. Electrical consumers can be directly connected and supplied with this energy.

The storage system of the plant consists of an electrolyzer, a hydrogen tank, a fuel cell and lead batteries (see table 1). In an electrolyzer hydrogen is produced from water using excess solar energy. The adjustment to the available excess energy is achieved through the controlled hydrogen current of the electrolyzer and grid frequency. When the energy demand of the electrical consumers is higher than the energy from the PV array the grid frequency drops. Below a frequency of 50 Hz the fuel cell is switched on. The fuel cell converts the stored hydrogen in electrical power. The lead batteries serve as short-term energy storages. They immediately compensate supply irregularities. The current controlled inverters of the PV array require a reference value in order to be fed into the island grid. A bidirectional, self-commutated battery inverter serves as grid aligner. On the AC side it regulates current, frequency and power. On the DC side it operates as battery charger with charging regulator and deep discharge protection by load shedding. The island grid inverter additionally converts direct current from the fuel cell and the batteries into alternative current of the island grid. The individual components of the system can be directly controlled and regulated by means of a PLC system (programmable logic controller).

Table 1: Technical specification of solar-hydrogen based autonomous electric power system.

PV Arrays	Power	8,6 kWp
	Modules	40 x IBC 215P SI, polycrystalline
Grid Tie Inverter	Type	2 x Sunny Boy 3800, SMA
Electrolyzer	Type	PEM, "Hogen 20“, Proton
	Max. Pressure	13,8 bar
	Power Consumption	max. 4 kW
	H_2-Production Rate	0,5 Nm³/hr
	Efficiency	approx. 36%
Hydrogen Storage	Pressure	200 bar
	Volume	50 l
Fuel Cell	Type	PEM, I-1000, ReliOn
	Power	1 kW
	H_2-Consumption	1 Nm³/hr (1kW)
	Efficiency	approx. 39%
Island Grid Inverter	Type	SI 4248FC, SMA bidirectional
	max. Power	4200 W
		230V, 50 Hz
Batteries	Type	VRLA, Hoppecke
	Capacity	140 Ah, 12 V
	Quantity	4 in series
	Weight	218 kg

24-Hour-test run

The functionality of the system was proved in several test runs. Figure 2 shows the measured values within a 24-hour-period from September 9 to 10, 2009, days on which irradiation values were considerably high. The load demand was based on an idealized single-household load profile. The total used solar module surface was 66 m², which is the equivalent of a power output of 8.6 kWp. The fuel cell supplied the loads at night. As irradiation values increased the performance of the fuel cell slowed down. During the day the power output from the PV array was so high that most of the time the electrolyzer operated at full load. As irradiation values declined in the evening the electrolyzer also slowed down and subsequently the fuel cell was activated again.

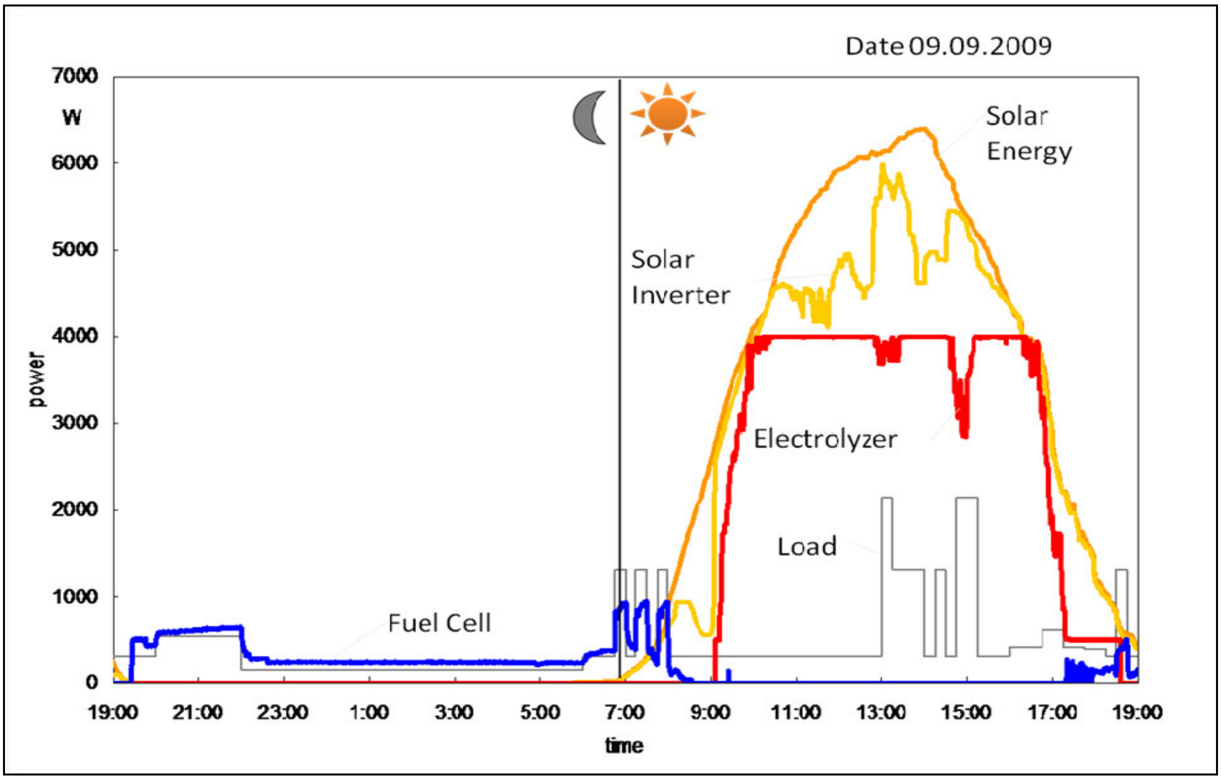

Figure 2: 24-hour-test run.

The PV array generated a total power of 38 kWh from 41 kWh of solar energy. The fuel cell supplied 5 kWh. The electrolyzer consumed 32 kWh and the regular load used 10 kWh. The batteries consumed 3-4 kWh/d (see figure 3).

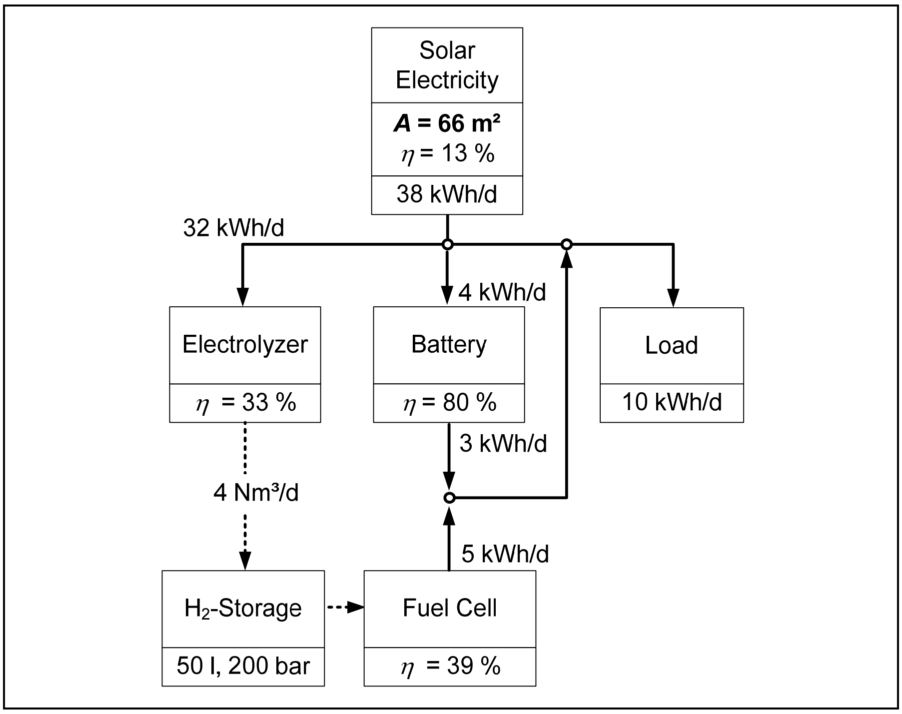

Figure 3: Energy flow diagram based on 24-hour-test.

3 Discussion

Power supply based on a hydrogen-battery system is environmentally friendly and sustainable. Such combined systems offer perfect supply security during winter, even independently from renewable energy sources. In comparison, battery systems can only compensate fluctuating energy from the PV array with a very large PV surface. In the case of a power failure over a longer period, an additional generator (e.g. diesel generator) is needed to supply the loads. The hydrogen-battery system, however, does not produce harmful emissions. Moreover thanks to smaller PV arrays, the costs for material and energy resources can be reduced.

Excess hydrogen storage can be used to complete partial charge cycles in lead batteries. While partial charges have no affect on hydrogen, they shorten the lifespan of the batteries. The combination hydrogen and battery provides a higher degree of cycle stability and ensures longer life spans of the batteries. This project demonstrates the advantages of stored energy from hydrogen in connection with the storage of fluctuating energy sources.

4 Conclusion

The selection of the components, the control of the system and the operational behaviour of the individual components have to be optimized.

In this connection future research will focus on island grid aligners in order to be able to store excess solar energy even more efficiently in the form of hydrogen. This is why the electrolyzer should be connected to the DC side of the grid aligner. Here it is recommended to use the stack voltage of the electrolyzer as the control variable.

The fuel cell and the electrolyzer currently require a total of approx. 600 W in standby mode. This should be reduced to a minimum. The components should possess autonomous switching behaviour to react to given input signals.

5 Outlook

The successful operation of the island grid demonstrates the functionality of the system. Further testing will focus on varying environmental and system parameters in order to verify optimization approaches. Special attention should be paid to improve the efficiency of the system so as to be economically competitive. Reliable models for dimensioning an island grid system must be developed further. Based on appropriate boundary conditions, hydrogen, as a long term energy store for excess electrical energy, can help opening up new fields of application for this very promising technology.

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