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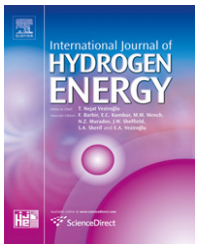

The wind/hydrogen demonstration system at Utsira in Norway: Evaluation of system performance using operational data and updated hydrogen energy system modeling tools

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ABSTRACT

An autonomous wind/hydrogen energy demonstration system located at the island of Utsira in Norway was officially launched by Norsk Hydro (now StatoilHydro) and Enercon in July 2004. The main components in the system installed are a wind turbine (600 kW), water electrolyzer (10 Nm^3/h), hydrogen gas storage (2400 Nm^3, 200 bar), hydrogen engine (55 kW), and a PEM fuel cell (10 kW). The system gives 2–3 days of full energy autonomy for 10 households on the island, and is the first of its kind in the world. A significant amount of operational experience and data has been collected over the past 4 years. The main objective with this study was to evaluate the operation of the Utsira plant using a set of updated hydrogen energy system modeling tools (HYDROGEMS). Operational data (10-min data) was used to calibrate the model parameters and fine-tune the set-up of a system simulation. The hourly operation of the plant was simulated for a representative month (March 2007), using only measured wind speed (m/s) and average power demand (kW) as the input variables, and the results compared well to measured data. The operation for a specific year (2005) was also simulated, and the performance of several alternative system designs was evaluated. A thorough discussion on issues related to the design and operation of wind/hydrogen energy systems is also provided, including specific recommendations for improvements to the Utsira plant. This paper shows how important it is to improve the hydrogen system efficiency in order to achieve a fully (100%) autonomous wind/hydrogen power system.

1. Introduction

Hydrogen can be used to store variable renewable energy, such as solar and wind energy [1,2]. Previous studies [3–6] show that there is a potential market for wind/hydrogen energy systems in remote areas and/or weak grids, specifically for (1) Stand-alone power systems and (2) Hydrogen vehicle fueling stations. The main motivation for applying hydrogen technology in remote areas is the notion that locally produced renewable hydrogen will be able to compete with traditional fossil fuels (e.g., diesel) sooner here than in more densely populated areas. The situation today is that remote communities are already experiencing relatively high fuel costs. Remote areas with favorable winds are therefore logical targets for wind energy based hydrogen systems.

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Nomenclature

Acronyms:

AC, DC	alternating current, direct current
BOP	balance of plant
CO_2, H_2	Carbon dioxide, Hydrogen
EES	engineering equation solver
FC	fuel cell
HHV	higher heating value
HYDROGEMS	HYDROGen Energy ModelS
IFE	Institute for energy technology
IGBT	insulated-gate bipolar transistor
NiCd	nickel cadmium
PEM	proton exchange membrane
R&D	research & development
RE	renewable energy
SAPS	stand-alone power systems
TRNSYS	TRaNsient SYstem simulation program
WECS	wind energy conversion system

Symbols & Units:

P	power, kW
υ	speed, m/s
h	hour
kVA	kilovolt–Ampere
kW, MW	kilowatt, Megawatt
ms	millisecond
m^2	square meters
Nm^3	normal cubic meters
€	euro

Several wind/hydrogen concepts and system designs have been studied over the past decade [4–9], and a few physical installations have been made [3,7,10–19]. An overview of the most known wind/hydrogen demonstration systems and pilot plants installed around the world the last decade is provided in Table 1. Most of the installations listed here are small-scale systems based on wind turbines with only few kWs and a DC-busbar stabilized by a battery bank. The most notable exception is the autonomous wind/hydrogen system at the island of Utsira (Norway), which provides power to 10 households via a local AC mini-grid [12,18]. Another relatively large system is the DC-based system serving the West Beacon Farm in Loughborough (UK) [13], which has a hydrogen storage capacity of about 2850 Nm^3, slightly larger than the 2400 Nm^3 installed at Utsira. Most of the systems listed in Table 1 were based on commercially available alkaline electrolyzers with rated hydrogen production capacities and operating pressures in the range of 0.2–10 Nm^3/h and 7–20 bar, respectively. The exceptions were the prototype PEM-electrolyzer at IFE (0.3 Nm^3/h and 15 bar) [16] and the prototype high-pressure alkaline electrolyzer in the PURE-project (3.6 Nm^3/h and 55 bar) [19]. In comparison, the hydrogen pressure and production capacity for the alkaline electrolyzer installed at Utsira was 12 bar and 10 Nm^3/h.

Table 1 – Overview of wind/hydrogen-systems installed world-wide, 2000–2008.

Year[a]	Location	Name of project	Refs.
2000	ENEA Research Centre, Casaccia, Italy	Prototype wind/electrolyzer testing system	[7]
2001	University of Quebec, Trois-Rivières, Canada	Renewable energy systems based on hydrogen for remote applications	[10]
2004	Utsira Island, Norway	Demonstration of autonomous wind/hydrogen-systems for remote areas	[12,18]
2004	West Beacon Farm, Loughorough, UK	HARI–Hydrogen and Renewables Integration	[13]
2005	Unst, Shetland Islands, UK	PURE–Promoting Unst Renewable Energy	[3]
2006	IFE, Kjeller, Norway	Development of a field-ready small-scale wind-hydrogen energy system	[16,17]
2006	NREL, Golden, Colorado, USA	Wind-to-hydrogen (Wind2H2) demonstration project	[14,15]
2007	Pico Truncado, Argentina	Wind/hydrogen demonstration plant	[11]
2007	Keratea, Greece	RES2H2 wind-hydrogen pilot plant, with H_2-storage in metal hydrides	[20]

a Approximate year of commissioning.

The overall motivation for the Utsira project is to demonstrate how renewable energy and hydrogen systems can provide safe and efficient power supply to communities in remote areas. The main goal for the project is to perform a full-scale demonstration and testing of a wind/hydrogen energy system [12]. After several years with concept development, system design, and project planning undertaken by several partners [21,22], the decision to build the Utsira plant was made in April 2003. The installations in place were mainly realized by Norsk Hydro (now StatoilHydro) and Enercon, the two main partners in the project. The Utsira plant was inaugurated in July 2004, is still in operation, and continues to play an important part in StatoilHydro's R&D on hydrogen technology [23]. A significant amount of operational data and experience has been collected since the commissioning of all of the systems during the winter 2004/2005 [18]. The main objective of this study is to evaluate the energy performance of the Utsira plant using actual operational data and an updated set of hydrogen energy system modeling tools. A thorough discussion on issues related to the design and operation of wind/hydrogen energy systems is also provided, including specific recommendations for improvements to the Utsira plant.

2. System description

The Utsira wind/hydrogen energy demonstration plant is located at the island of Utsira, ca. 20 km off the west coast of Haugesund in Norway. This island was picked because of its