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Testing of a small-scale stand-alone power system based on solar energy and hydrogen

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Abstract

An experimental small-scale stand-alone power system based on hydrogen and solar energy has been tested. The system performance and operational experience are reported. Future expansion of the test-facility is taken into consideration using solutions with wide working ranges. The test-facility is designed for testing of individual components, for subsystems, and for complete power system operation. The complete power system in this study consists of a 4.8 kW programmable power supply, 1.5 kW electrolyser, a hydrogen purification unit (99.999% H_2 quality), a 14 Nm^3 H_2 metal hydride storage, a 0.5 kW fuel cell, a 300 Ah lead-acid battery, and a 0.6 kW programmable load. Possible applications for such small-scale power systems are mountain cabins, remote islands, and telecommunication stations, among others. The basic idea in this particular power system configuration was to make it as simple as possible; the fuel cell and the metal hydride unit were air-cooled, and the components were connected in parallel without DC/DC converters. The only control action possible in the power system (presented in this study) was to switch the components either ON or OFF. However, connecting the components electrically in parallel without DC/DC converters gives no degrees of freedom regarding the ability to regulate power and voltage levels of the different components. Air-cooled metal hydrides might fail to deliver hydrogen due to poor heat transfer.

Keywords: Hydrogen technology; Electrolyser; Fuel cell; Metal hydride; Control strategy

1. Introduction

The motivation for the construction of the hydrogen stand-alone power system (HSAPS) test-facility was to develop a flexible test-facility for investigations of the properties of the different components and different configurations. The experimental data obtained from the characterisation of the components were combined with models from the HYDROGEMS (Ulleberg and Glöckner, 2002) library applied for development of detailed empirical computer models (Matlab/Simulink). The computer model of the HSAPS was used for development of control strategies (Miland, 2005). An other benefit of having a physical system is the practical experience, operating a small-scale HSAPS, the test-facility has also a great value as a demonstration site for the industry, educational institution, and research communities.

2. System of reference

To test a HSAPS in real-time throughout a whole year is time consuming, and large energy storages (the battery and the metal hydride in this case) are needed. To investigate the performance of the laboratory HSAPS, it was convenient to cycle the system based on the laboratory hydrogen storage size. A data set consisting of solar energy profiles for seven days was chosen. The solar data was measured with a time resolution of 2 min at Kjeller (60° N), Norway during July and August 2000. The sequence of the days in the solar profile was combined in order to approach a relative seasonal/periodic behaviour during a week in

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Nomenclature

BAT battery
C control matrix
ELY electrolyser
FC fuel cell
HHV higher heating value (for H_2: 3.54 kWh/Nm^3 at 273.15 K and 0.1013 MPa)
HSAPS hydrogen stand-alone power system
HYDROGEMS HYDROGen Energy ModelS
LHV lower heating value (for H_2: 3.00 kWh/Nm^3 at 273.15 K and 0.1013 MPa)
MH metal hydride
MPPT maximum power point tracker
N normal conditions (273.15 K and 0.1013 MPa)
PEM proton exchange membrane
PV photovoltaic

System parameters
BAT_{SOC} battery state-of-charge
$H_{2,SOC}$ hydrogen state-of-charge
$I_{PV-Load}$ PV current subtracted by current drawn by the load
$Pred_{PV-Load}$ predicted average PV power subtracted by predicted average load within next 2 h

Control parameters
$BAT_{ELY,ON}$ threshold value defining BAT_{SOC} as high or neutral
$BAT_{FC,ON}$ threshold value defining BAT_{SOC} as low or neutral
$H_{2,High}$ threshold value defining $H_{2,SOC}$ as high or neutral
$H_{2,Low}$ threshold value defining $H_{2,SOC}$ as low or neutral
$I_{Balance,+/-}$ threshold value defining $I_{PV-Load}$ as positive or negative
$Pred_{ELY,ON/OFF}$ threshold value defining $Pred_{PV-Load}$ as positive or negative

real-time, in the subsequent analyses denoted as the test-week.

The hydrogen subsystem consisting of the electrolyser, the H_2-storage, and the fuel cell will in this work be referred to as the hydrogen-loop. The HSAPS-lab was configured as sketched in Fig. 1 throughout the test-week. The power supply emulated battery discharging, while the electronic load emulated battery charging. Component details are given in Table 1. Power to the hydrogen purification unit is supplied from the grid, but is taken into account in the annual simulation runs to show the overall energy balance. A detailed study of energy consumed by the H_2 purification unit is given in (Miland et al., 2003).

2.1. Input data and forcing functions

The actual input to the power supply was a text file containing electrical current and voltage values from a computer model of the PV array with maximum power point tracker (MPPT) processed with the measured solar data. The input to the programmable load was a text file with electrical current values. The load voltage depended on the voltage level of the component supplying the load. The resulting power from the emulated PV array and the resulting power required by the load are shown in Fig. 2. The two first days are representative for winter days with general low solar energy, while the third day is a typical

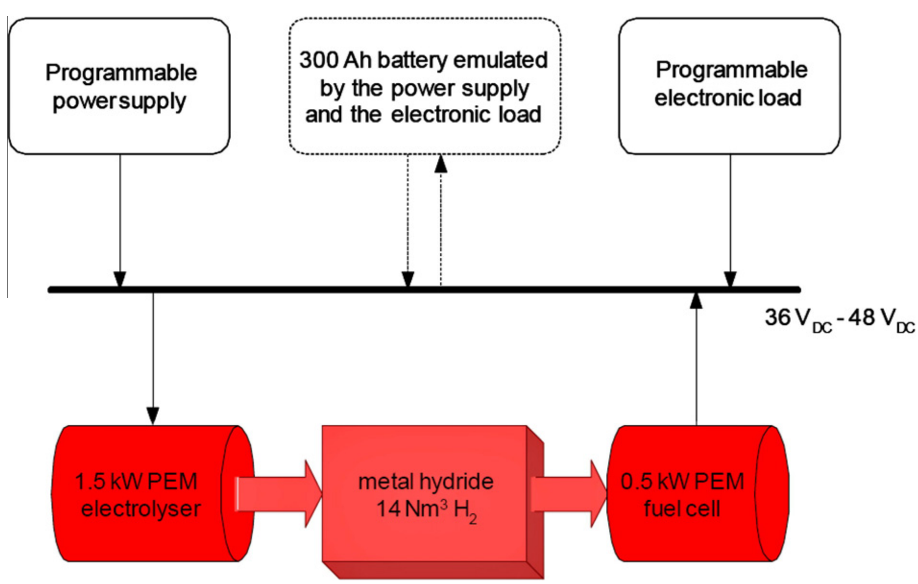

Fig. 1. Schematic of the laboratory HSAPS used during the test-week.