Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Solar hydrogen power system for isolated passive house

Miri Motalleb, Ankica Đukić, Mihajlo Firak*

Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, 10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 20 July 2015
Received in revised form
14 September 2015
Accepted 15 September 2015
Available online 31 October 2015

Keywords:
Solar energy
Passive house
Hydrogen
PEM fuel cell
Alkaline electrolyzer
Mathematical modeling

ABSTRACT

Solar hydrogen power system for supplying isolated passive house with utility power energy and hydrogen fuel for personal transport has been established and discussed. Commercially available components such as photovoltaic module, proton exchange membrane fuel cell stack and electrolyzer stack were acquired. Appropriate control logic was developed. MATLAB/Simulink software has been used to simulate control logic and system components. The proof of the control logic and components models has been performed by simulations predefined scenarios, i.e. with and without solar irradiance and with given energy demands by the user. All of that can be used as valuable tool for any autonomous solar hydrogen system design of passive house.

Introduction

Renewable energy sources (RES) are attracting high attention as an alternative source of energy. This is not only due to the diminishing fossil fuel sources, but also due to environmental pollution and global warming. In the long run, there will be no alternative to an optimized tapping of the potentials of RES. Especially, the utilization of solar energy through photovoltaic (PV) cells connected into PV modules and solar thermal power plants play a key role. Isolated (not connected to electric grid) households energy usage should be first of all based on energy saving, i.e. passive house concept [1] should be deployed. The rest energy demand for house heating and cooling should be accomplished by solar thermal systems and demand for electricity by PV systems. These two systems are usually physically nondependent of each other, but they are connected by various heat flows in the passive house. For example, electrical losses are output heat flows from appliances, but input heat load for cooling system or additional heat flow that helps to heat the house. Through the passive house concept a considerable energy savings compared to the existing one can be obtained. This comparison is given in Fig. 1.

A small heating load was roughly equivalent with an annual space heat requirement of 15 kW h m^{-2}. Hence, passive houses need about 85% less space heat than new buildings designed to the various national buildings in Europe. The energy saving potential for a single residence goes together with carbon dioxide (CO_2) emission reductions of about 50%–

* *Corresponding author*. Tel.: +385 1 6168 218.
E-mail address: ankica.djukic@fsb.hr (A. Đukić).
http://dx.doi.org/10.1016/j.ijhydene.2015.09.134

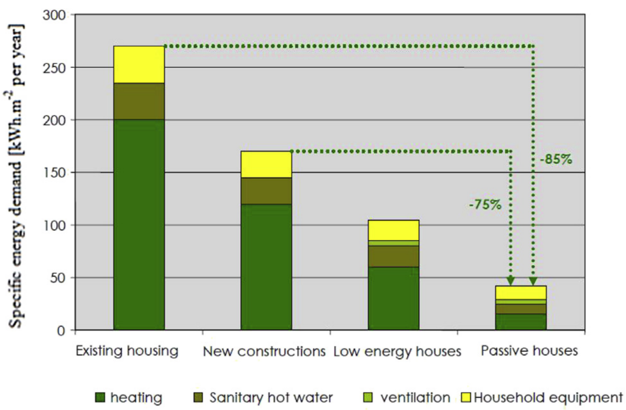

Fig. 1 – Comparison of energy consumption of: passive house vs. other buildings [1].

65%. So if we want to design autonomous solar hydrogen power system, for the conventional system it would be at least two times larger for PV array, fuel cell stack, electrolyzer stack and all other relevant components. The main control problems arise due to large variances of PV cells output power under different solar irradiance levels [2–5]. To overcome this problem, PV power plants used to be integrated with other power sources or storage systems such as battery, and/or hydrogen based system (electrolyzer, hydrogen storage and fuel cell). These devices must store excess solar energy and subsequently deliver power at the desired time and rate. The energy storage device that is most commonly used with PV systems today is the battery, but hydrogen based technology has already become highly competitive. Under assumption of increased part of using solar energy in entire energy consumption and developing of technology of hydrogen production and utilization, it is necessary to conceive solar hydrogen autonomous system for supplying isolated household with electric power and energy for personal transport (ASVS + T) [6–8]. To design efficient passive house many factors need to be taken into account, as the most important one is climate in the selected area [9,10]. In this work it is assumed solar hydrogen system to cover household electricity load and to ensure enough hydrogen as fuel for personal transport (typically an pick up track). It is consisted of the PV modules, batteries, electrolyzer stack, hydrogen storage, hydrogen compressor and controller. As energy storage means, battery and compressed hydrogen gas storage (including electrolyzer and fuel cell) have both advantages and disadvantages that were not discussed here. But the fact that electrolyzer, fuel cell and controller need to have electricity source to start, demands battery inclusion as a sine qua non. In this system, electricity generated in the PV modules is sent to battery and excess electricity to the electrolyzer stack to produce hydrogen. Hydrogen is stored to be utilized in stationary Proton Exchange Membrane (PEM) fuel cell stack for household electricity load demand and to be further compressed and stored in storage tank of the hydrogen powered personal vehicle when required. The heat that is produced by fuel cell and electrolyzer stack can be used appropriately in heat and mass flow management system of the household [11–14] but that use was not considered here. Power system of this complexity obviously needs to be automatic controlled. Due to that, appropriate control logic has been developed.

Methodology and solution strategy

The major components of supposed power system are PV modules, batteries, an electrolyzer stack, hydrogen storage, a PEM fuel cell stack, household electricity load, hydrogen compressor and transport vehicle hydrogen supply, i.e. additional hydrogen needed. A control system is employed to monitor the state of the system, control power and hydrogen flows, except the hydrogen flow to compressor during vehicle hydrogen storage filling what is controlled manually. That is the reason why in further text mathematical model of the compressor is described but not used. An excess of solar energy can be used in electrolyzer stack for hydrogen production. Produced hydrogen is stored into the storage tank for subsequent use in PEM fuel cell stack. The household has electrical appliances, lights and Direct Current (DC) motors. All of that are supposed to be as DC loads. DC loads are then treated as Ohmic resistance that affects voltage and current of the PV modules, batteries and fuel cell stack. The whole power system is controlled by automatic control provided by controller defined by control logic. The power system is consisted of commercially available components: PV modules [15], battery [16] and fuel cell stack [17]. The electrolyzer stack was produced only once for research purpose from Hystat company and already published data were used in this work [18]. This allows a real input data to be used in simulation. To define and simulate solar hydrogen generation subsystem some results from Refs. [5,7,19–21] have been used. Such one model with real input data can produce real outputs according to the chosen scenario. Components for the house power system and computer modeling and simulation were developed in MATLAB/Simulink computer code. Simulation was performed for each component separately to check its model correctness and all together with control logic (control system or simply controller) included, using predefined solar irradiance and electrical load time profiles. It should be emphasized that the scope of this work is to present developed model, but not its validation in comparison with real measurement data during certain living period in a passive house.

Power system components models

PV module

The model of a PV module consisted of one string of 36 cells in series was presented by mathematical model in equation (1).

$$I_{PV} = I_{ph} - I_s\left(\exp\left(\frac{(U_{PV} + I_{PV}R_s)}{(mU_t)}\right) - 1\right) \tag{1}$$

$$f(I_{PV}) = I_{ph} - I_s\left(\exp\left(\frac{(U_{PV} + I_{PV}R_s)}{(mU_t)}\right) - 1\right) - I_{PV} = 0 \tag{2}$$

where:

I_{PV}/A is PV module operating current; I_{ph}/A is photo current; I_s/A is saturation dark current; U_{PV}/V is PV module