INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 1195–1209

Available online at www.sciencedirect.com

ScienceDirect

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

Review

A review of fuel cell based hybrid power supply architectures and algorithms for household appliances

V. Boscaino*, R. Miceli, G. Capponi, G. Ricco Galluzzo

Department of Energy, Information Engineering and Mathematical Models (DEIM), University of Palermo, Viale delle Scienze, Building 9, 90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 26 July 2013
Received in revised form
26 October 2013
Accepted 31 October 2013
Available online 4 December 2013

Keywords:
Fuel cell
Renewable energy
Hybrid power supply
Power management
Hydrogen

ABSTRACT

Nowadays, renewable power system solutions are widely investigated for residential applications. Grid-connected systems including energy storage elements are designed. Advanced research is actually focused on improving the reliability and energy density of renewable systems reducing the whole utility cost. Source and load modeling, power architectures and algorithms are only a few topics to be addressed. Designers have to carefully deal with each subtopic prior to design efficient renewable energy systems. In the literature, each topic is separately discussed and the lack of a unique reference guide is clear to power electronics designers. In this paper, each design step including source and load modeling, hybrid supply architectures and power algorithms, is carefully addressed. A review of existing solutions is presented. The correlation between each topic is deeply analyzed. Guidelines for system design are given. This paper can be referenced as a detailed review of renewable energy system design issues and solutions.

1. Introduction

Nowadays, renewable power system solutions are widely investigated for residential applications. Reducing fossil fuel and energy saving are the primary goal. The use of renewable energy sources is worldwide promoted. Yet, due to limited energy and power density, stand-alone configurations are not well-suited for high power applications. Grid-connected systems including energy storage elements as well are actually designed. Designers aim at improving system reliability while reducing the cost of the whole power plant. Several issues are to be solved by advanced research [1]. Source and load equipment modeling, hybrid power supply architectures and power management algorithms are only a few topics to be addressed. Designers have to carefully deal with each subtopic prior to designing high performance renewable energy systems. Source and load accurate modeling is key to a successful conclusion of the overall design process. Power system architectures and power management algorithms design is closely related to and heavily affected by the specific source

* *Corresponding author*. University of Palermo, Department of Energy, Information Engineering and Mathematical Models (DEIM), Power Applications Laboratory, Viale delle Scienze, Building 9, 90128 Palermo, Italy. Tel.: +39 09123860272; fax: +39 091488452.
E-mail address: valeria.boscaino@dieet.unipa.it (V. Boscaino).

http://dx.doi.org/10.1016/j.ijhydene.2013.10.165

and load equipment. In the literature, each topic is separately discussed and the lack of a unique reference guide is clear to power electronics designers.

In this paper, fuel cell based hybrid power supply for household appliances are addressed. Each design step is carefully addressed. Several effective solutions to each involved topic from source and load modeling to power management algorithms are presented. The correlation between each topic is deeply analyzed. Effects of models accuracy on system performances are highlighted. The importance of system simulation to shorten the design process avoiding experimental failure is highlighted. Guidelines for hybrid power supplies are given.

This paper can be referenced as a deep overview of renewable energy system design issues and solutions.

2. Fuel cell based power supplies

Fuel cells are widely promoted since electricity is produced as far as hydrogen is supplied. Yet, the transient response of fuel cells is worsened by electrochemical reaction rate. Since platinum is used as active catalyst, saving cost of the whole fuel cell stack usually results in poor dynamic performances of the stack itself. Therefore, fuel cells are not the most suitable choice in a stand-alone configuration. For practical implementations, fuel cells are used as primary source of energy whereas the peak power demand is usually supplied by auxiliary sources. By coupling a high energy density and a high power density source, performances of the composite source can be optimized. Load power sharing and power management algorithms are key to achieve high performances. Coupling configurations and power management algorithms as well are the basis of the overall design process. Elementary load power sharing algorithms are based on intrinsic features of each basic source. The load is entirely supplied by the fuel cell under steady-state conditions while peak power demand is supplied by the auxiliary source.

Yet, this elementary power management algorithm seldom meets design requirements in terms of system cost and size. Even if the control algorithm features quite low complexity of implementation, it usually leads to oversize both the main and the auxiliary source further increasing the system cost. In the last few years, advanced solutions have been investigated. Indeed, the choice of a proper power management algorithm is closely related to load power consumption profile and heavily affected by the selected hybrid configuration. In the literature, passive and active hybrid configurations are usually distinguished. Passive hybrids are based on the parallel connections of main and auxiliary sources. In a passive configuration the choice of power management algorithms is heavily limited. Active hybrid configuration provides the introduction of energy conversion stages between main and auxiliary sources. Great design flexibility is therefore ensured and several configurations can be implemented. By means of switching converter, power sharing between main and auxiliary sources can be successfully implemented. Passive hybrid configurations are no longer implemented in small-scale power plants and only reserved for extremely low power applications. In spite of their low complexity, passive hybrids do not ensure high performances. In reference [2], a detailed comparative analysis of a battery/supercapacitor hybrid in passive and active configuration is reported.

Power architectures and management algorithms are closely related to the specific application. The analysis of the load power consumption profile is a key target. For example handheld devices exhibit a highly pulsed power consumption profile, the current slew rate and peak value are extremely high. For notebook the current slew rate reaches 100 A/μs as well. For the specific purpose, the main limit is the limited reaction rate within the fuel cell stack and therefore the limited transient response to peak power demand. Therefore, for portable applications supercapacitors which feature higher power density than batteries are usually preferred.

In the last few years, fuel cell powered handheld devices have not been further investigated due to difficulties arising from hydrogen transportation.

Nowadays, the academic and industrial research is focusing on automotive and household appliances limiting hydrogen storage related issues. Power consumption profile requirements of household appliances are not so pressing. Yet, designers aim at limiting the amount of energy which is drawn from the electrical grid while saving hydrogen cost and consumption. Therefore, energy storage elements are required and power architectures as well as power management algorithms are oriented to save utility cost, size and hydrogen consumption. The academic and industrial research is now focused on innovative algorithms and architectures to meet all conflicting requirements. In this paper, household appliances are addressed.

3. System modeling

Architecture and algorithms are designed on the basis of load power consumption profile. Accurate load modeling is required to choose a proper hybrid architecture and power management algorithm. Independently of the specific load device or equipment and power level, the load power consumption profile should be accurately modeled. Likewise, source modeling is essential to simulate the entire power supply as closely as possible to its effective behavior validating hybrid architecture and algorithms since the simulation step thus shortening the design process.

In the literature, source and load modeling are widely addressed topics. Yet, the importance of a proper simulation environment is often neglected. Designers aim at simulating the entire system in a unique simulation environment. Source and load models have quite different features and are derived independently of each other. Circuit, Artificial Neural Networks (ANN), mathematical equations or state machines are only a few implementations. The corresponding simulation environment is the best suited for the specific implementation. System engineers have to match these heterogeneous models in a unique simulation environment. Several co-simulation options are available in MATLAB environment. Circuit models, analog and digital sections as well as state machine models or ANN based models can be simulated in MATLAB/Simulink by means of co-simulation toolboxes