3º Seminário Internacional Torres Vedras (Portugal) April 29-30, 2010
Hydrogen Energy and Sustainability- Advances in Fuel Cells and Hydrogen Workshop

A Power Management Strategy for a Stand-Alone Photovoltaic/Fuel Cell Energy System for a 1kW Application

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Abstract

In this paper a power management strategy is presented for a stand-alone photovoltaic (PV)/fuel cell (FC) energy system. PV is the primary power source of the system and an FC-electrolyzer combination is used as a backup and a long-term storage system. The energy in the hybrid system is balanced by the common dc bus voltage regulation. A simple hysteresis voltage control is used for dc bus voltage regulation. In this way, the fuel cell and the electrolyzer can be protected from unnecessary utilization or irregular operation (reduction of frequent start-ups and shutdowns). Simulation results obtained using Matlab and Simulink are presented to verify the effectiveness of the proposed control algorithm.

Keywords: *renewable energy, stand-alone system, hydrogen production, power management strategies, hysteresis control*

1 Introduction

The combined effect of the rising prices of conventional energy and the growing awareness of impact of environmental pollution has stimulated great interest in alternative and clean energy sources. Renewable resources such as solar, wind and tidal have the potential to provide clean energy, but their inherent intermittency and variability precludes their use for continuous supply of energy. To meet a continuous demand, a renewable energy system must either be integrated with other energy sources and/or include a means of storing energy.

The performance of a hybrid energy system is highly dependent on the power management strategy. In most of the proposed power management strategies, however, the key decision parameters are selected and set without delving into their effect on the overall system performance [1-2].

In this paper, an overall power management strategy is designed for a hybrid energy system to coordinate the power flows while ensuring efficient operation of the different energy systems. A stand-alone hybrid energy system consisting of PV, FC, electrolyzer and battery bank is considered. PV is the primary power source of the system to take full advantage of renewable energy, and the FC-electrolyzer combination is used as a backup and long-term storage system. In order to account for short-term power fluctuations in the system, a battery bank is also used. Simulation results are presented to demonstrate the effectiveness of the proposed power management strategy.

2 Hybrid power system configuration

Fig. 1 shows the system configuration for the proposed stand-alone hybrid energy system. The renewable PV power is taken as the primary source while the FC-electrolyzer combination is used as a backup and a long-term storage system. All the energy systems are connected in parallel to a common dc bus line through appropriate power electronic interfacing circuits. When there is excess solar generation available, the electrolyzer is activated to initiate hydrogen production, which is delivered to hydrogen storage tanks at low pressures. When there is deficit in power generation, the FC will start to produce energy using hydrogen from the reservoir tanks. In order to alleviate the power fluctuations in the common dc-bus, a battery bank was considered.

Nomenclature

H_2SOC_{min}	Hydrogen storage minimum limit of state-of-charge, %
H_2SOC_{max}	Hydrogen storage maximum limit of state-of-charge, %
P_{load}	load power demand, W
P_N	excess or shortage of power, W
P_{PV}	produced power from the photovoltaic array, W
P_{min_el}	electrolyzer minimum operating power level, W
P_{max_el}	electrolyzer maximum operating power level, W
V_{bus}	dc bus line voltage level, V
V_{min}	battery bank minimum acceptable voltage level, V
V_{fc_st}	Voltage level to activate the fuel cell, V
V_{fc_end}	Voltage limit for fuel cell operation, V
V_{el_end}	Voltage limit for electrolyzer operation, V
V_{el_st}	Voltage level to activate the electrolyzer, V
V_{max}	battery bank maximum acceptable voltage level, V

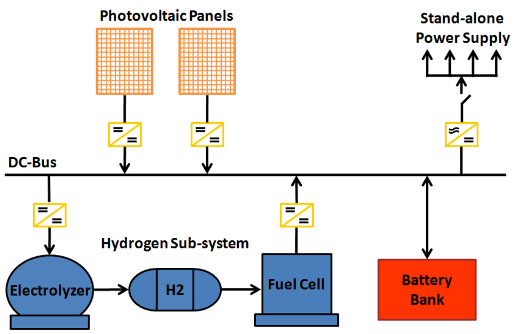

Fig. 1. System configuration of the proposed stand-alone hybrid energy system.

3 Power management strategy

The main requirements of the proposed power management strategy for the autonomous stand-alone hybrid energy system are to satisfy the load demand under variable weather conditions and to manage the power flow while ensuring efficient operation of the different energy systems. The management strategy should primarily use the power generated by the PV system to satisfy the load demand. Any excess of power should be used to produce hydrogen through water electrolysis and any shortage of power should be met by the FC and/or the battery bank. The inherent variability in the solar generation produces variability in the operation of the fuel cell, the electrolyzer and the battery bank. Since stable operation of these energy systems is vital for efficiency, lifetime and cost, the management strategy should mitigate the effects of power fluctuations on their operating pattern. In this implementation, simple hysteresis control is used for this purpose.

The key decision parameters for the proposed hysteresis control are shown in Fig. 2.

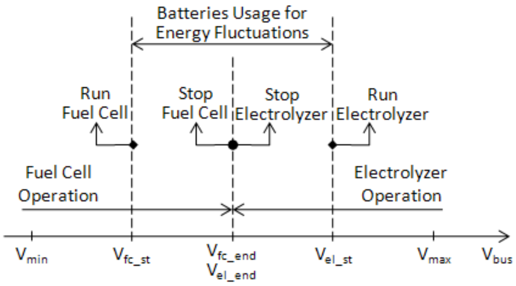

Fig. 2. Representation of the operation of the stand-alone hybrid power system.

The control of power flow from sources and to/from storage devices is based on the values of the dc bus voltage, V_{bus}, the state-of-charge of the hydrogen storage tank, H_2SOC, and the net power, P_N, which is calculated as the difference between the power generated by the PV system, P_{PV}, and the power demand of the user, P_{load}:

$$P_N = P_{PV} - P_{load} \tag{1}$$

Basically, at any given time, any excess PV-generated power ($P_N>0$) is supplied to the electrolyzer to produce hydrogen and/or to the battery bank to charge it. The electrolyzer is activated at V_{el_st} provided that there is enough power available and $H_2SOC<H_2SOC_{max}$. Since the electrolyzer is allowed to operate at the minimum power level of P_{min_el}, in the case when $P_N<P_{min\_el}$ the differencial power is provided by the battery bank as long as $V_{bus}>V_{el\_end}$. If $P_N>P_{max\_el}$ the electrolyzer utilizes power equal to P_{max_el} and the extra power P_N-P_{max_el} is used to charge the battery bank without exceeding V_{max} to avoid overcharging.

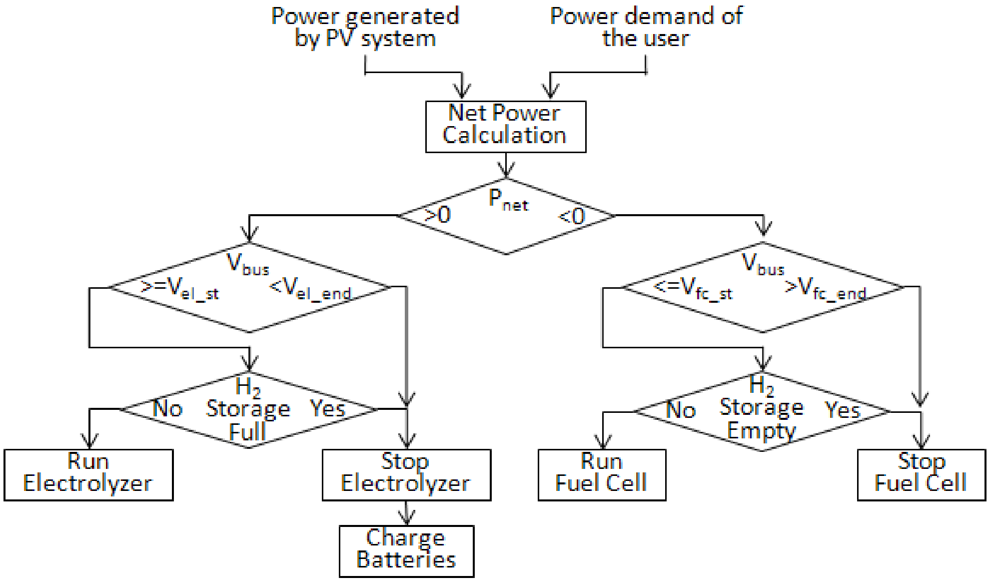

Fig. 3. Logical block diagram for the power management strategy.

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When there is a deficit in power generation ($P_N<0$), the deficit is covered by the battery bank or the FC. If $V_{bus} \leq V_{fc\_st}$ and $H_2SOC > H_2SOC_{min}$, then the FC is set to provide the necessary power to meet the load demand and to charge the battery bank without exceeding its charging current limit. If $V_{fc\_st} < V_{bus} < V_{fc\_end}$ and in the previous time step the FC was operating and still shortage of power exists ($P_N<0$), then the FC does not shut down and continues to operate until the V_{bus} reaches the limit V_{fc_end}.

In the range $V_{fc\_st} < V_{bus} < V_{el\_st}$ and provided that neither the electrolyzer nor the FC are operating, the battery bank is charged ($P_N>0$) or discharged ($P_N<0$) depending on the net power level. Fig. 3 shows the detailed logical diagram for the proposed power management strategy.

4 Simulation results

To test the effectiveness of the proposed power management strategy, a 1kW PV/FC hybrid energy system is simulated in Matlab/Simulink over a 7-day time period for the power profiles shown in Fig. 4. The system operating parameters used in the simulation are listed in Table 1. The PV, FC, electrolyzer, hydrogen and battery storage were represented by models developed in [3].

Fig. 5 presents the dc bus voltage correlation with the FC and electrolyzer power. One can see that whenever the dc bus voltage crosses the thresholds V_{el_st} and V_{fc_st}, the electrolyzer and the FC are activated, respectively. On the other hand, whenever the electrolyzer or FC are operating and the dc bus voltage crosses the thresholds V_{el_end} and V_{fc_end}, the electrolyzer and the FC are deactivated, respectively. This figure also shows that the dc bus voltage is well controlled and a regular operating pattern of the FC and electrolyzer have been achieved.

Finally, the hydrogen storage state-of-charge is maintained at a reasonable level as seen in Fig. 6.

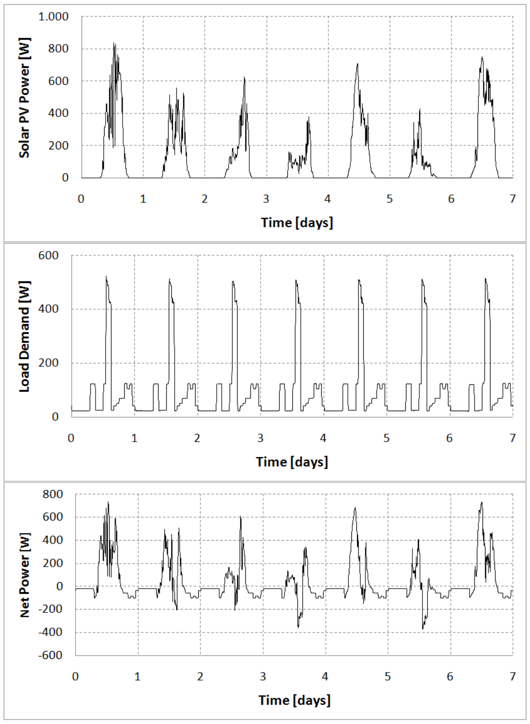

Fig. 4. Power profiles for a 7-day time period.

Table 1. System operating parameters.

PV array	
Power rating	1kW
Fuel cell	
Rated power	500W
Electrolyzer	
Rated power	500W
Minimum operating power level (P_{min_el})	125W
Maximum operating power level (P_{max_el})	500W
Hydrogen storage tank	
Volume	$3m^3$
Initial state-of-charge (SOC)	50%
Minimum limit of SOC (H_2SOC_{min})	30%
Maximum limit of SOC (H_2SOC_{max})	95%
Battery	
Capacity	300Ah
Rated voltage	24V
Minimum acceptable voltage level (V_{min})	23V
Voltage level to activate FC (V_{fc_st})	26.2V
Voltage limit for FC (V_{fc_end}) and electrolyzer (V_{el_end}) operation	26.6V
Voltage level to activate the electrolyzer (V_{el_st})	27V
Maximum acceptable voltage level (V_{max})	29.4V

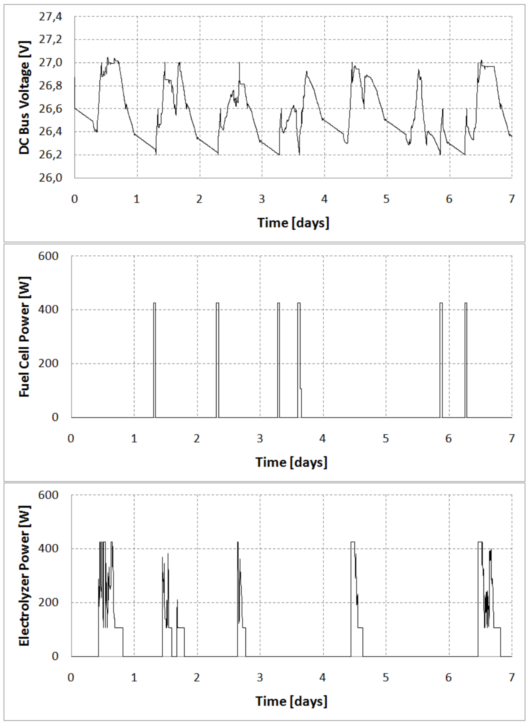

Fig. 5. DC bus voltage and electrolyzer and fuel cell power profiles for a 7-day time period.

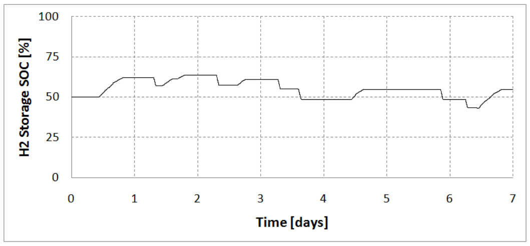

Fig. 6. Variation of hydrogen storage state-of-charge for a 7-day time period.

5 Final remarks

A power management strategy has been developed for a PV/FC hybrid energy system that optimizes the overall system performance. The simulation results shows that the control strategy is effective in protecting the battery bank from overutilization and properly regulating the operating pattern of the FC and electrolyzer. Further simulation studies need to be performed in order to optimize the dc bus voltage thresholds of the hysteresis band.

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