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Hybrid Three-Port DC–DC Converter for PV-FC Systems

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Abstract

The proposed a hybrid power systems using PV generators hydrogen for energy storage purposes. In this case, the hydrogen is produced by an electrolyzer powered by the electrical energy excess from the renewable energy source.

The produced hydrogen feeds then a fuel cell (FC) system, which will supply the city of Brest in high-load demand period. Otherwise, it will be used as a secondary source of energy. For such king of hybrid power systems, the sources can be optimally sized with different techniques and then selected from commercially available components.

INTRODUCTION

Stand-alone systems are independent of utility grids and commonly employed for satellites, space stations, unmanned aerial vehicles and domestic applications.

Such systems require storage elements to accommodate the intermittent generation of solar energy. Over the years, research effort has been directed toward improving the power conversion efficiency as well as the power density by weight and the power density by volume. Fuel cells (FCs) are emerging as a promising supplementary power sources due to their merits of cleanness, high efficiency, and high reliability. Because of long startup period and slow dynamic response weak points of FCs [1], mismatch power between the load and the FC must be managed by an energy storage system.

Batteries are usually taken as storage mechanisms for smoothing output power, improving startup transitions and dynamic characteristics, and enhancing the peak power capacity.

In hybrid electric vehicles (HEVs), fuel cell (FC) stacks can be used as clean energy sources [6]. FCs is energy sources that directly convert chemical energy to electrical energy. FCs generates electric energy and, rather than storing it, continues to deliver the energy as long as the fuel supply is maintained. However, FCs has the drawbacks of slow dynamic response and high cost per output power. Combining such energy sources introduces a PV/FC/battery hybrid power system [7]. In comparison with single-sourced systems, the hybrid power systems have the potential to provide high quality, more reliable, and efficient power. In these systems with a storage element, the bidirectional power flow capability is a key feature at the storage port. Further, the input power sources should have the ability of supplying the load individually and simultaneously.

In general, FCs and batteries have different voltage levels. Therefore, to provide a specific voltage level for the load and control power flow between the input sources, a power converter is required for each of the input sources; this increases the price, mass, and losses.

To overcome these drawbacks, multiport converters have been used in hybrid power systems.

The basic boost converter is modified and integrated; however, in practice, the voltage gain of the MIMO boost converter is limited owing to the losses associated with the inductor, filter capacitor, main power switch, and rectifier diode [2]. Because of a very high duty ratio, the output rectifier conducts for an extremely short time during each switching cycle, thus resulting in major reverse-recovery problems and an increase in the rating of the rectification diode. The switch-off loss due to the rectifier diode affects the efficiency, resulting in the electromagnetic interference problem that is severe in this condition.

The proposed structure utilizes only four power switches that are independently controlled with four different duty ratios. Utilizing these duty ratios facilitates controlling the power flow among the input sources and the load. Powers from the input power sources can be delivered to the load individually or simultaneously. Moreover, the converter topology enables the storage element to be charged or discharged through both input power sources.

PROPOED HPS STRUCTURE

Description of the studied system

The proposed and studied system comprises photovoltaic panels, a fuel cell stack and a storage system. Power management unit (PMU) allows the coordination between the different energy sources such as PV panels electrolyzes and fuel cells (Fig. 5). Generally, PV subsystem works as a primary source; it converts solar irradiation into electricity provided to a DC bus. Hydrogen is used by the second working subsystem (the fuel cell stack) which produces electrical energy to supply the DC bus.

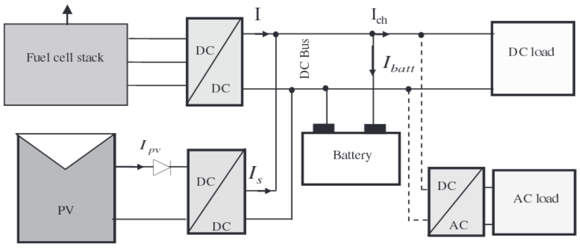

Fig. 1: Description of a hybrid photovoltaic battery fuel cell

Modeling of the studied system

Modeling of the PV

The model studied in this work is represented by an equivalent circuit. This one consists of a single diode for the cell polarization function and two resistors (series and shunt) for the losses (Fig. 3). Thus, it can thus be named “one diode model”. This model runs under the technical characteristics of the solar cells given by the manufacturers (data sheets) [3].

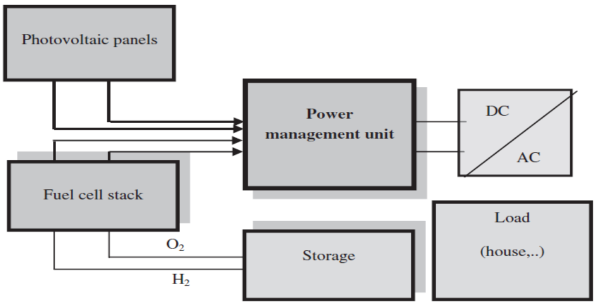

Fig. 2: Description of the overall system

The Ipv (Vpv) characteristic of this model is given by the following equation:

Ipv = Iph-Id-Irsh……………….1

or, developing the terms Id and IRsh:

$$I_{pv} = I_{ph} - I_0\left[\exp\left(\frac{q(V_{pv}+R_s\cdot I_{pv})}{AN_sKT_j}\right)-1\right] - \frac{V_{pv}+R_s\cdot I_{pv}}{R_{sh}} \quad \text{……………2}$$

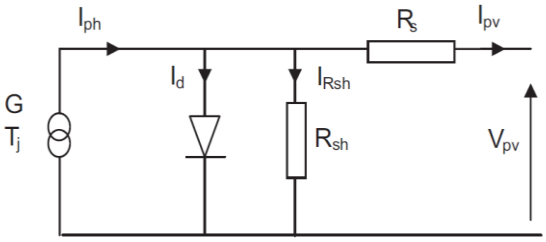

Fig 3: Simplified equivalent circuit of solar cell

There are different methods to solve Eq. (2), each method leads to an approximate mathematical models. The different mathematical models generally include parameters that are provided by photovoltaic modules manufacturers [5]. For this, several methods have been proposed in the literature to determine different parameters. The module is made of 72solar cells connected in series to deliver a maximum power output of 110 W. The variation in both the Ipv -Vpv and Ppv -Vpv characteristics with irradiance level are simulated.

Modeling of fuel cell PEMFC

It is necessary to define the different circuits of a fuel cell system to simplify the modeling and control of each circuit. The cell system is composed of the heart cell associated with all necessary ancillaries to the operation of a fuel cell in an embedded application. Fig. 5 shows all functions that are present in a fuel cell system. The Moto-compressor is composed of an air compressor and an electrical machine. Generally it is a permanent magnet synchronous motor (PMSM). An air compressor supplies directly each stack, and the flow of the air is regulated through the control of rotational speed. The compressors used in such applications are volumetric type because they can easily control the outflow [5]. These types of compressors are classified into two categories: reciprocating compressors and rotary compressors. In fuel cell applications, it is the twin-screw rotary compressor types which are used because they do not require lubrication. The inputs of the compressor model are the rotation speed u and the discharge pressure Ps (imposed by the pressure control).The outputs are the mass flow and torque compression. Another useful parameter for the operation of the stack is the gas temperature at the output of the compressor (Fig. 5).

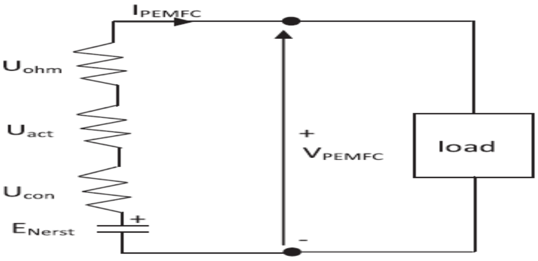

Fig. 4: Electrical representation of a PEMFC

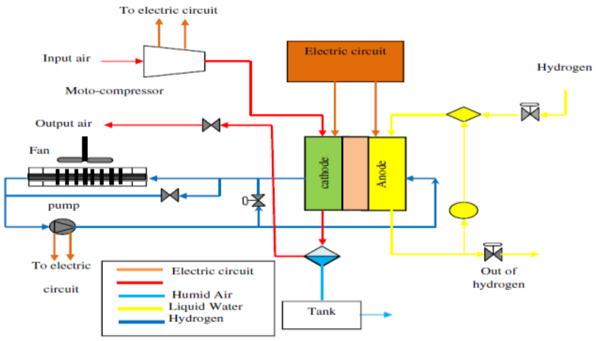

Fig 5: Diagram of a PEMFC

Power management

A control strategy for power management is needed. The total power is calculated as

Ptotal = Ppv – Pcomp –Pload

Any excess of PV power is supplied to the electrolyzer to generate hydrogen that is delivered to the hydrogen storage tanks through a gas compressor [6]. The power balance equation given by: (Ptotal> 0).

Ppv = Pcomp + Pload +Pelectrolyser

If there is a deficit in total power (Ptotal< 0), the PEMFC start producing energy for the load using hydrogen from the storage tanks, Thus, in this case the power balance equation can be written as

Ppv+ PPEMFC =Pload

We Note that between 10:30 and 14:00, the PV generator works and provides the power required. This is due to the light curve, the rest of the day, the PEMFC delivers this power. We can note from the obtained results that the proposed hybrid system works as proposed by the power management.

SIMULATION RESULTS

Hybrid PV/Fuel Cell System integrated to AC micro grid

The proposed system is represented in the simulink form under the Matlab. A complete system model composed of a hybrid energy source which is composed of Fuel Cell, PV Array and battery, Boost regulator , Inverter and load. PEMFC model, PV cell connected to a Ni-Metal Hydride battery model has been developed and simulated using MATLAB/Simulink program. This software offers the advantage allowing the user to view the system at different levels, such that the models are easily connected together. The parameters can be changed during simulation, and the results from different simulations are eventually analyzed.

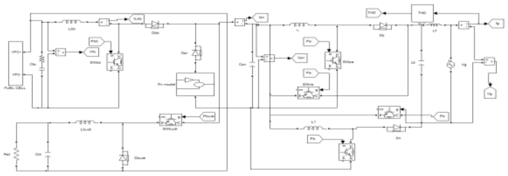

Fig 6: Simulation circuit of the proposed Hybrid PV-Fuel cell system

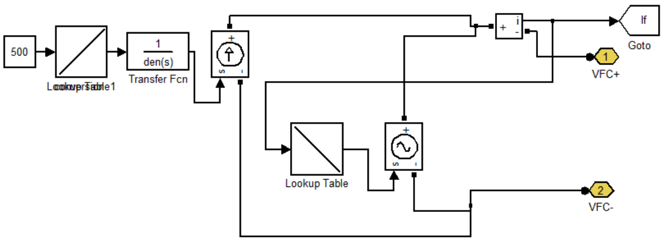

Fig 7: Fuel cell design

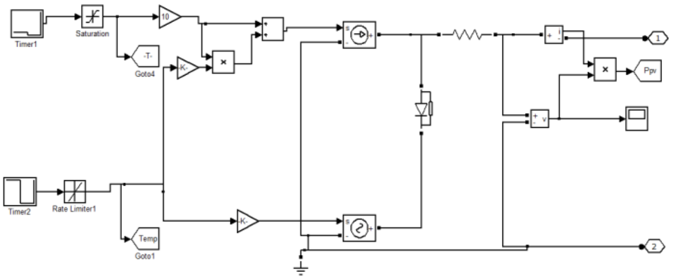

Fig 8: PV-cell Design

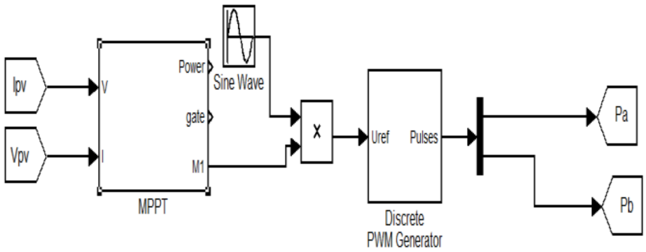

Fig 9: Inverter control system

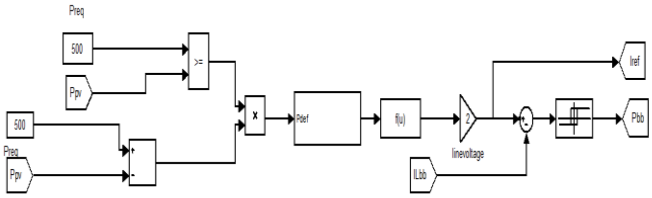

Fig 10: control system for Fuel cell fed DC/DC converter

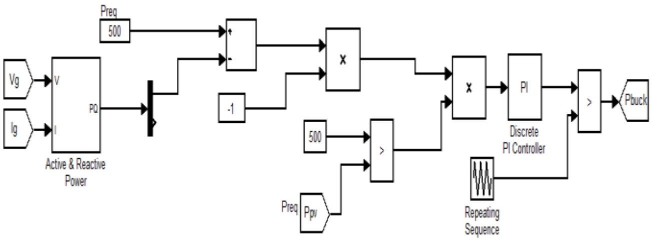

Fig 11: Control algorithm for Excess power control to DC load

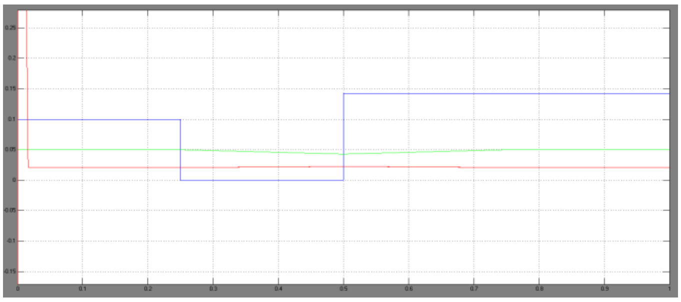

Fig 12: Simulation waveform of PV irradiance, Temperature, and AC grid current THD

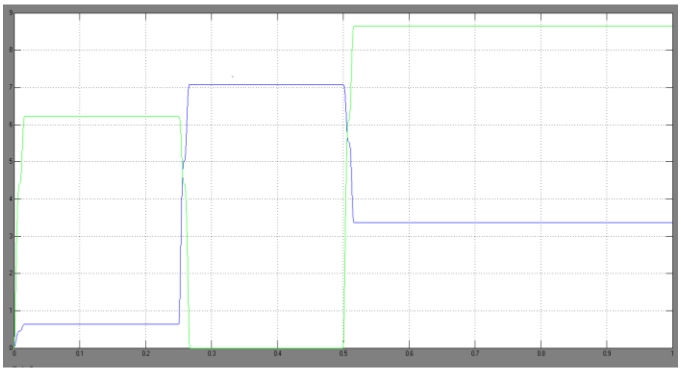

Fig 13: Fuel cell current and PV cell current

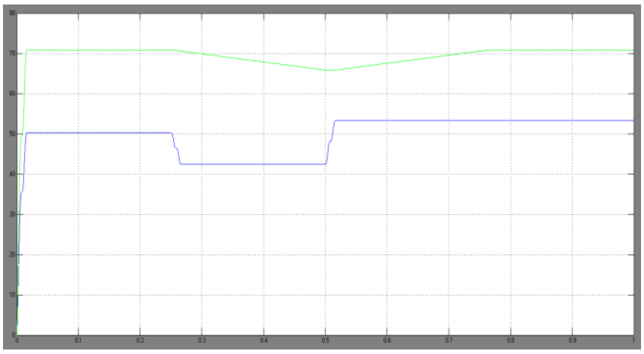

Fig 15: Fuel cell voltage and PV cell voltage

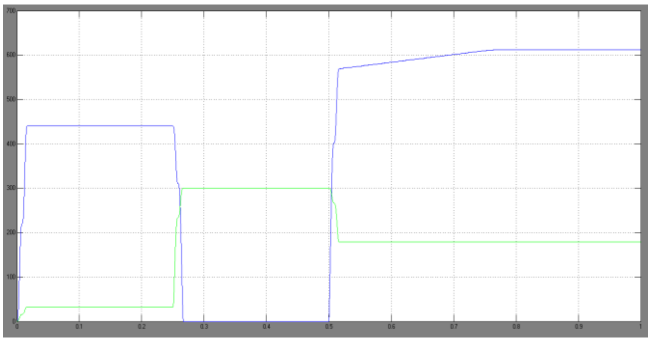

Fig 16: PV cell power and fuel cell power

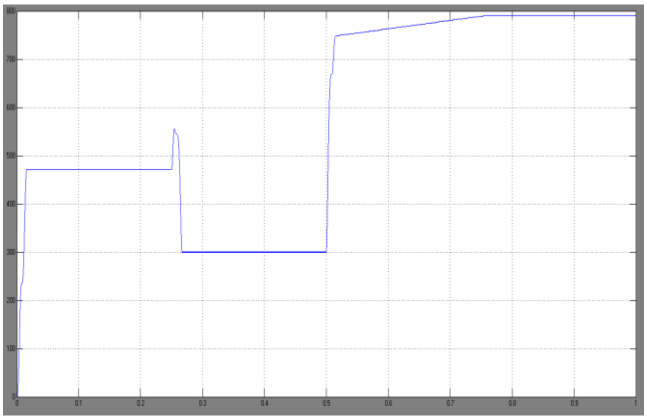

Fig 17: Total power (PV cell + Fuel cell)

CONCLUSION

This paper dealt with the optimal design of a stand-alone hybrid PV/FC power system without battery storage to supply the electric load demand. The proposed optimal design study was focused on economic performance and was mainly based on the loss of the power supply probability concept. The study using the total net present cost has clearly shown that the proposed hybrids power system and in particular fuel cells are a viable alternative to diesel generators as a non-polluting reliable energy source with a reduced total cost of maintenance. It has also been shown that a fuel cell generator could efficiently complement a fluctuating renewable source as solar energy to satisfy growing loads.

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