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Sizing of Photovoltaic System Coupled with Hydrogen Storage Based on the ORIENTE Model

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The future belongs to renewable energy sources, and satisfying the energy growing demand for sustainable energy sources must be one of the highest priority for research in the energy field. The systems based on these sources have a limited ecologic impact because they only use hydrogen and solar energy. The solutions based on renewable energy are very promising when it comes to supply energy to isolated sites, with problems related to their location. Concerning hydrogen-based solutions, the objectives are not only to improve the performances of hydrogen production and storage solutions, but also to associate them effectively with renewable energy sources [1, 2].

PEPITE (study and experimentation of intermittent energy management using electrochemical technologies) is a project endorsed by the French PAN-H research program (action plan on hydrogen and fuel cell) supported by ANR (French Research National Agency). This project started in January 2008 for three-year duration. The aim of the project is to evaluate different system architectures and energy management strategies for hybrid systems based on renewable energy sources coupled with hydrogen for different applications. The system is composed of a PV array, an electrolyzer (PEM), a fuel cell (PEM), batteries, gas and water storage solutions, and also an electrical architecture to couple the whole system and the load. Finally the interest of this project is to propose and to evaluate solutions for isolated sites or for grid-connected applications supplied by PV/FC/EI system [3, 4]. In this project, the sizing of each sub-system has to guarantee an optimal system efficiency [5-12]. An exclusive sizing tool based on a numerical optimizing code named ORIENTE (Optimization of Renewable Intermittent Energies with Hydrogen for Autonomous Electrification) was developed under MatlabTM software [13], and assumes sequentially running time. A weather station located in Cadarache (CEA, France) will represent the load which will be supplied by the designed PV/FC/EI hybrid system for the demonstration. In our case, the demonstration system (fig.1) will be composed by a PV array, a PEM fuel cell and PEM electrolyzer with their auxiliaries, batteries, and storage tanks for H₂, O₂ and H₂O, and associated converters. In this hybrid system, batteries are transparent energetically at normal functioning.

They are also used in normal regime to maintain the potential of the BUS, to assure the start-up/stop in correct conditions and finally to smooth the electrical power from the fuel cell and the electrolyzer system. They have to be in charge before the functioning of the system. In this paper batteries are not used as means of storage (in opposition with other projects or they are considered like a short-term energy storage), but they must be sized regarding smoothing of electrical power. Thus, for our project, hydrogen is used as means of short and long-term storage too.

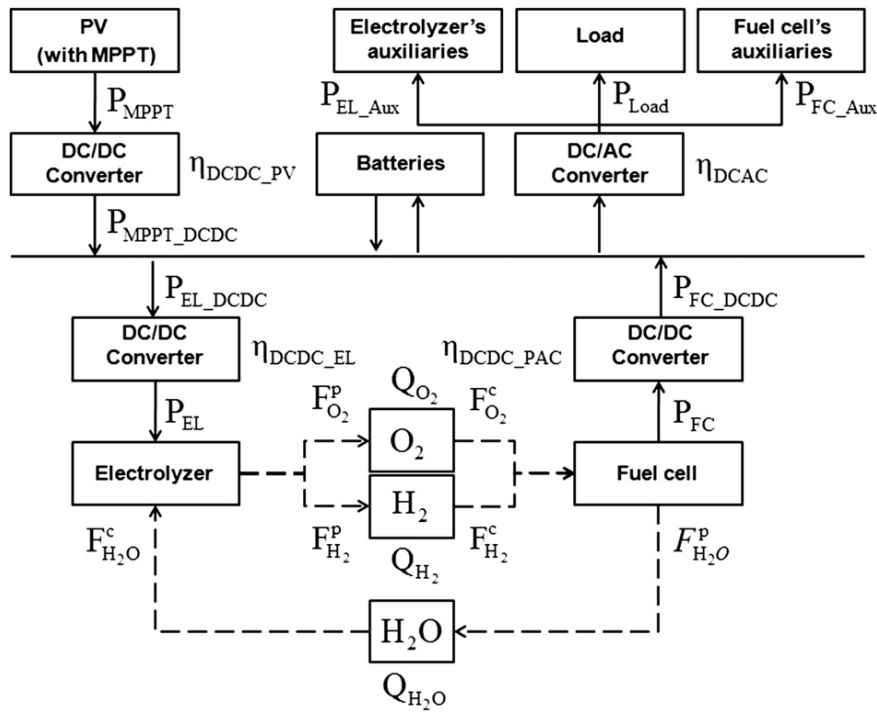


Figure 1: Representation of the studied PV/H₂ hybrid system.

The load that must be fed by the energy system is represented by a meteorological station (weather pylon) with the consumption of its control command sub-system, the thermal management of the PV/FC/EI system; and the gas storage's auxiliaries, corresponding to 6500W of constant power operating 24/24 hours. The global hourly solar radiation (45° tilted) and ambient temperature data were measured (local time), a few meters away from the weather station of Cadarache (France). The data are available from the 1st July 2002 to the 30 June 2003 (8760 hours). From the data, monthly means of hourly values are represented (Fig.2) only computed on sunshine periods.

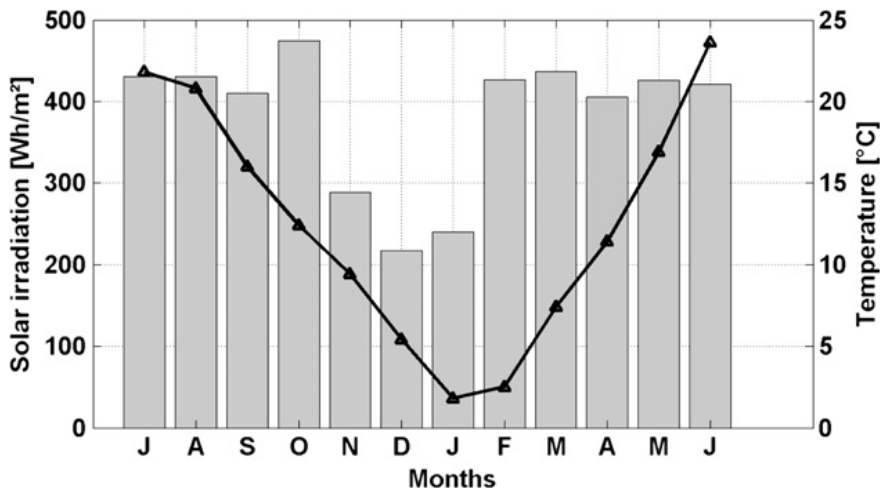


Figure 2: Meteorological data monthly mean.

The Fig. 3 describes the proposed flow control. The PV array supplies in priority the load *via* the DC/AC converter. In the case of an excess of PV power (above the power threshold of the electrolyzer) and a non-full hydrogen storage, this extra power will be transferred to the electrolyzer *via* its DC/DC converter. If the electrolyzer cannot absorb it (under the power threshold or full storage) then the “transparent” batteries could absorb it to a certain limit depending of their sizing. And if the batteries are full, then the PV array is totally shut down. When the PV array is not able to satisfy the load power, the fuel cell supplies the complementary amount of power. If the power required for the fuel cell is under its power threshold or if the gas storage is empty, the “transparent” batteries could supply it to a certain limit depending of their sizing. And if the batteries are fully discharged, then the system is shut-down. The last case should not happen because we size exactly the system to avoid this scenario. Nevertheless it is necessary for the electric safety of the system.

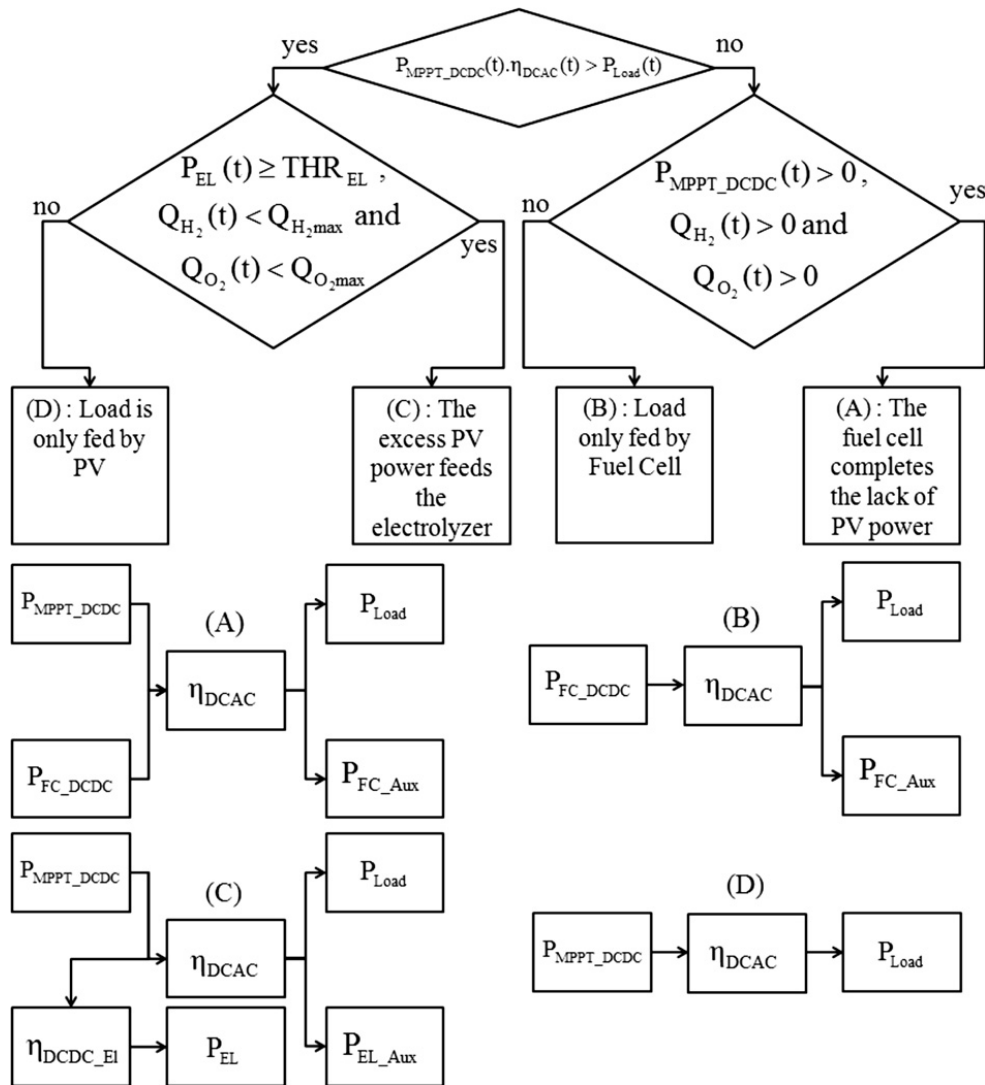


Figure 3: Proposed flow control.

For an optimization of the system components, ORIENTE uses the hourly weather data (solar radiation and ambient temperature) and the hourly load profile. The internal parameters of each sub-system are already in the model, with the possibility to modify them. The optimization follows this way:

1. We define minimum and maximum PV powers, with corresponding to numbers of modules.
2. DC/DC converter associated to PV array is sized according to the maximum power that able to deliver (according to the number of modules)
3. Fuel Cell is sized according to the maximum power that the load can need, by considering efficiencies of the converter associated to the FC, the DC/AC converter, and the auxiliaries' consumption. By using the active area of an elementary fuel cell and the operation potential on V-I curve. The optimized parameter is the number of elementary cells in series. It gives us the FC power to be installed. The DC/DC converter associated to the FC and the DC/AC converter are sized according to the maximum power to be delivered.
4. The electrolyzer is sized according to the maximum excess power that the PV can produce, by considering the efficiencies of the converter associated to the electrolyzer, the DC/AC converter, and the auxiliaries' consumption. By using active area of an elementary electrolyzer cell and the operation current on V-I curve (maximal potential on the curve which we wish that the electrolyzer can work). The optimized parameter is the number of elementary electrolyzer power to be installed. The DC/DC converter associated to the electrolyzer is sized at the same time according to the maximum power to be absorbed.

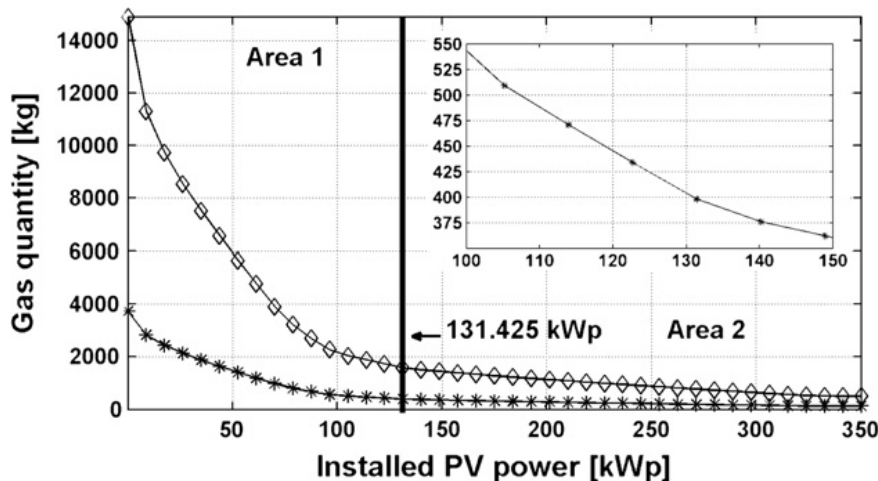


Figure 4: Optimization sizing curve (1 year period).

Fig. 4 represents the optimization curves of the PV/FC/EI system. The higher the installed P_{PV} power is, the lower the size of the gas storage tank for the required autonomy (the range of the hydrogen amount is between 3725 Kg and 398 Kg for an installed PV power respectively equal to 0 and to 131.425 kW, and 398 Kg to 125 Kg for a PV power between 131.425 and 350.175 kW). This figure can be divided into two parts. The limit is the point

where the PV power is such as the system consumes and produces the same amount (fig.5). When $P_{PV}=131.425$ kWp, about 2050 kg of H_2 are both produced and consumed. In the first area, the system is unsustainable. Operating a second year with the same sizing and the same load and the same meteorological profile would require a gas refueling to be sustainable. Beyond the line (area 2), the system is sustainable and the gas storage would never be empty.

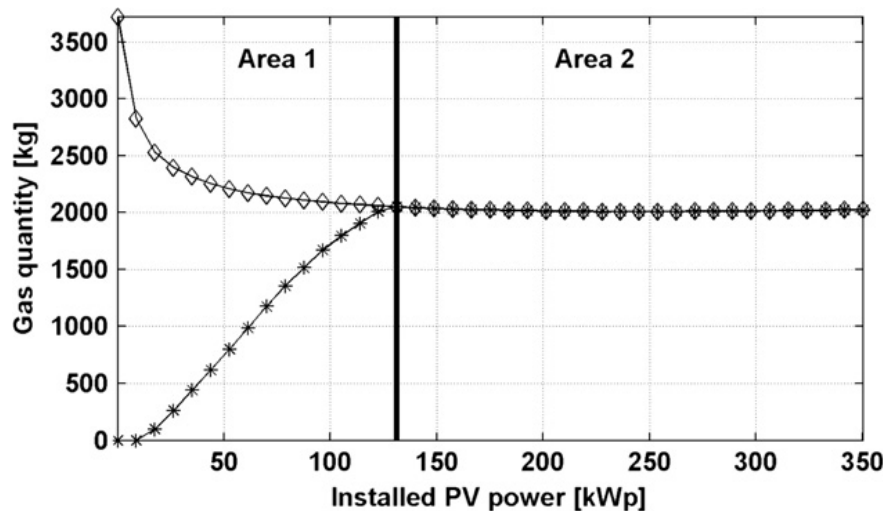


Figure 5: H_2 consumption (- \diamond -) and production (- * -) curves in kg (1 year period).

In conclusion we showed that we are able to determine a “sustainable” point for such a system in terms of sizing. Moreover ORIENTE makes it possible to describe in details the energy exchanges within such a complex system. A 24/24 hours system needs huge components, so an economic study will be necessary in order to know if the system cost and if such a configuration are economically acceptable. This study is currently continuing to evaluate the economic part and the interest of a hydrogen chain at this power level compared with storage *via* batteries alone.

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