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A Hybrid Distribution Generating System Based on Wind/Fuel cell Power Generation Systems with Energy Storage Capability

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ABSTRACT: This project proposes an integrated wind and fuel power generation system fed to an ac power grid or connected with Battery energy storage using a dc micro grid. A bidirectional dc/dc converter is proposed to achieve the integration of both wind and fuel power generation systems. The wind power generation system simulated by a permanent-magnet synchronous generator (PMSG) driven by a wind turbine (WT) is connected to the dc micro grid through a VSC of PMSG. The fuel cell power generation system driven by an Electrolyzer interconnected to the dc micro grid. A BESS is connected to the dc micro grid through a bidirectional dc/dc converter. To achieve stable power flow (or power balance condition) and load demand control of the dc micro grid under different operating conditions, a battery is connected to the dc micro grid through a bidirectional dc/dc converter, while an ac grid is connected to the dc micro grid through a bidirectional grid-tied inverter and a transmission line.

KEYWORDS: Wind Energy. Hybrid Energy System, Fuel Cell, Power management

I.INTRODUCTION

To overcome the stress of high electricity demand in mainstream utility grids, a combination of renewable energy and decentralized energy system, called distributed generation (DG) has been introduced. In recent years, DG systems which are installed near load centers have seen rapid developments and promise many advantages, such as low investment, high operating efficiency, low loss, and high reliability [1]. The limited reserves of fuel oils and their unstable prices have significantly increased the interest in renewable energy sources. The alternative energy sources are non-polluting, free in their availability, and continuous. The motivation behind the use of renewable energy sources is the reduction of CO2 emissions. This is especially true in isolated, standalone, small islands where the access to renewable energy sources is the only solution to meet their energy needs.

Today, wind and PV generators are utilized in such applications as water pumping, lighting, electrification of remote areas and telecommunications. For remote systems like radio telecommunication, satellite earth stations, or at sites that are far away from a conventional power system, the hybrid generation systems have been considered as preferred [2]. It is essential that some part and an increasing part, of future electrical energy research and development be concerned with so called ―nonconventional ―methods of generation Wind- solar PV and fuel cell power generations are visible options for future power generation. Besides being free, they are free of recurring costs. They also offer power supply solutions for remote areas, not accessible by grid power supply Today around 30,000 wind turbines and more than 1,00,000 off-grid solar PV systems are installed all over the world. Wind and solar hybrid model with proper storage system have been keen interest for the last few years. Fuel Cells (FC) in combination with electrolyzer (for hydrogen generation) and hydrogen storage tanks are being considered for energy storage. In this paper a hybrid model of solar / wind & fuel cell is developed and compared with the earlier model of solar/wind/battery system. The simulation circuit will include all realistic components of the system.

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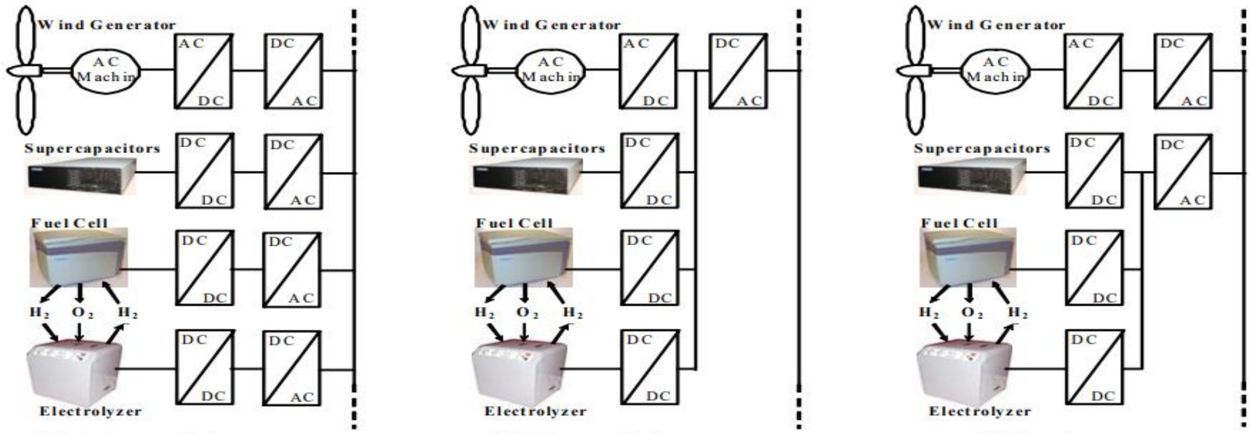
II.STRUCTURE OF THE STUDIED HYBRID POWER SYSTEM

The structures of Hybrid Power System (HPS) can be classified into two categories: AC coupled and DC-coupled. In an AC-coupled HPS, all sources are connected to a main AC-bus before being connected to the grid (Fig.1a). In AC-coupled structure, different sources can be located anywhere in the microgrid with a long distance from each other. However, the voltage and the frequency of the main AC bus should be well controlled in order to ensure the stability of the DG and the compatibility with the utility network [7]. In a DC-coupled HPS, all sources are connected to a main DC-bus before being connected to the grid through a main inverter (Fig.1b). In a DC-coupled structure, the voltage and the frequency of the grid are independent from those of each source. However, not all HPSs can be classified into AC or DC-coupled system, since it is possible to have both coupling methods (Fig.1c), then a Mixed HPS is obtained. In this case, some advantages can be taken from both structures. In this paper, we use the DC-coupled structure as shown in Fig.1b. The DC-coupled structure is flexible and expandable since the number and the type of the energy sources may be freely chosen. Even more, the grid frequency is independent from the sources through the use of the DC bus. The grid voltage is also independent from the DC-bus voltage and each source's voltage through the use of different power converters. So even if both the control structure and the power management are developed properly for a specified hybrid power system, the number and the type of the power sources do not alter the global control structure of the HPS and the main idea of the power management.



(a) AC-coupled structure (b)DC-coupled structure (c)Mixed structure

Figure 1: Structures of hybrid power systems for distributed generation

III. Representation OF WECS

A classical wind energy conversion system consists of a 3-blade turbine, a gearbox, an electrical machine, a three-phase rectifier, a DC-bus capacitor, a three-phase inverter, line filters which are connected to the grid through a grid transformer [6].

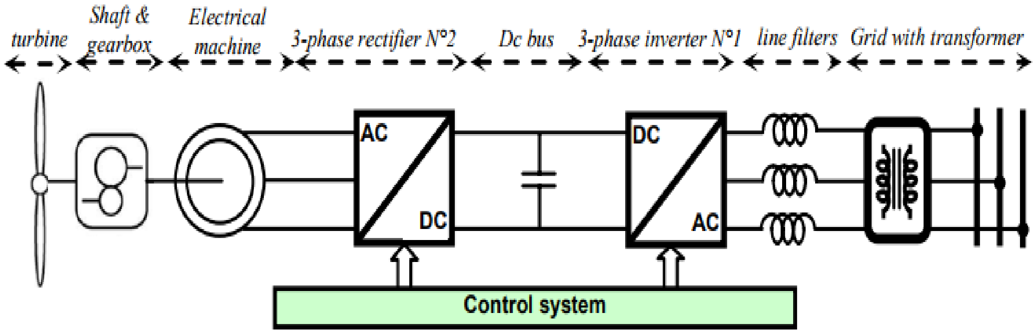


Figure 2: A classical variable-speed wind energy conversion system

When the wind energy conversion system works in MPPT strategy, the power, which is delivered to the grid, is very fluctuant [4].

Wind: The wind is modeled by a mechanical source (oval pictogram), which sets the wind velocity (V_{wind}) to the blades. Turbine: The turbine is modeled as a mechanical converter (triangular pictogram). The torque (T_{tur}), which is produced by the turbine, depends on the wind velocity (V_{wind}) and on the blade pitch angle (β):

A Wind Turbine (WT) cannot fully capture wind energy. Then, the output power of the wind-turbine is described as

$$P_{turbine} = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v^3$$

where, ρ is the air density (kg/m3), R is the blade radius (m), CP is the performance coefficient of the turbine which is a function of the pitch angle of rotor blades β (in degrees) and v is the wind speed (in m/s). The tip-speed ratio λ is given by:

$$\lambda = \frac{w_m R}{v}$$

Here R and w_m are the blade length (in m) and the wind turbine rotor speed (in rad/sec), respectively. The wind turbine mechanical torque output Tm given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda,\beta)v^3\left(\frac{1}{w_m}\right)$$

A generic equation is used to model the coefficient of power conversion $C_p(\lambda, \beta)$ based on the modelling turbine characteristics described as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

The coefficient of power conversion and the power are maximums at a certain value of tip speed ratio called optimum tip speed ratio λ_{opt}. Therefore, the maximum value of $C_p(\lambda, \beta)$, that is max C_p = 0.41, isachieved for λ_{opt} = 8.1 and for $\beta = 0^0$.

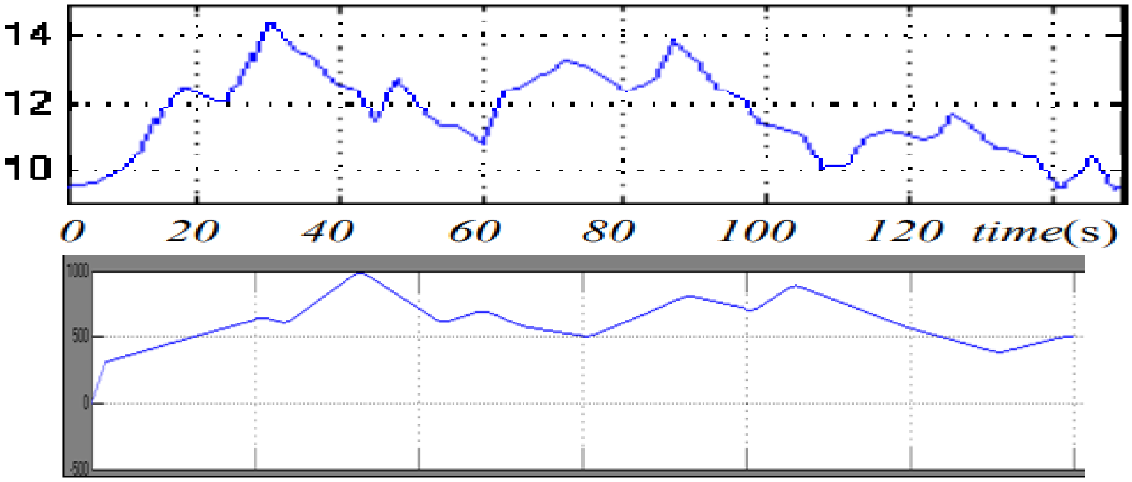


Figure 3: Wind speed (m/s) and generated wind power (w)

IV. PEMFC

Proton Exchange Membrane Fuel Cell (PEMFC) or Polymer Electrolyte Fuel Cell is based on a solid polymer electrolyte. Fast start-up times, low temperature operation and high power densities make them an easy to use technology especially for portable or transport applications. CO poisons the catalyst and the hydrogen fuel has to be very pure. Because the polymer membrane has to be kept well humidified for good proton conduction, water management is one of the critical aspects of successfully running a PEMFC [3].

Operating principles

Depending on the type of fuel cell and the used fuel, the reaction mechanisms may be different from each other. We choose PEM fuel cells to consider the operation description; moreover the main concept remains the same as for the other types of fuel cells. Within the PEM fuel cells, hydrogen and oxygen are converted into water while generating electricity. A schematic diagram of the processes occurring in a PEM fuel cells is shown in Fig. 4.

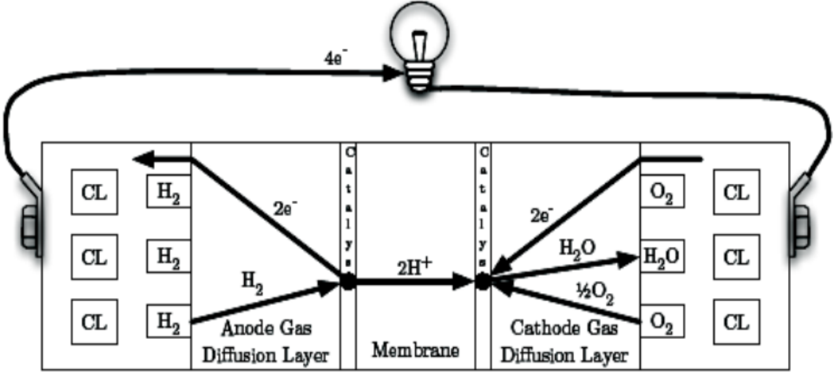


Figure 4: Schematic representation of a PEM fuel cell

Both reactant gases are supplied under pressure into the flow channels of the plate. At the anode side the hydrogen oxidation reaction forms protons and electrons:

$$H_2 - - - - - \rightarrow 2H^+ + 2e^-$$

Released protons and electrons are transferred through the membrane to the cathode catalyst layer and the external electrical load, respectively [8]. At the cathode side the oxygen is consumed by the oxygen reduction reaction along with the protons and electrons and liquid water is produced as the product with heat:

$$\frac{1}{2}o_2 + 2H^+ + 2e^- - - - - \rightarrow H_2o + Heat$$

As a result, the overall chemical reaction of the fuel cell is represented as follows:

$$H_2 + \frac{1}{2}o_2 - - - \rightarrow H_2o + Heat + \ Electricity$$

In order to technically exploit such a reaction, the two chambers are separated through an electrically insulating (i.e. no electron conduction) and gas-impermeable membrane electrolyte assembly, which is capable of conducting protons. The area in contact with the membrane is called catalyst layer, which is covered with a platinum catalyst on both anode and cathode sides [5].

Adjacent to the catalyst layers on both sides of the membrane is a porous, electrically conducting gas diffusion layer. It allows reaction gases (i.e. hydrogen and oxygen) to flow to the reaction sites on the catalyst layer and product water to flow back out.

Electrolyzer System

The system control can be simplified as shown in Fig.5.

Power conversion: The electrical power is controlled by a power conversion system, which consists of a stable voltage source, a DC chopper, a filter L_{el} and a filter C_{el}.

Hydrogen handling: The hydrogen is sent to a metal hydride with a constant pressure, so the hydrogen pressure in the electrolyzer is regulated with an electrovalve (open or closed).

Oxygen handling: The oxygen is outlet into the atmosphere and the oxygen pressure in the electrolyzer is also regulated with an electrovalve. It should be closed to the hydrogen pressure in order to reduce the membrane's mechanical stress.

Water management: The water is supplied by a circulating pump with a constant flow, which is sufficient for the reaction requirement and the system cooling need.

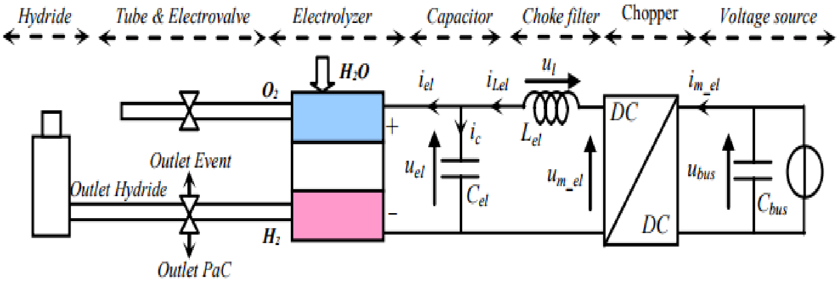


Figure 5: Block diagram of the simplified electrolyzer system.

V.SIMULATION RESULTS

A simulation of the active wind generator has been built to test the different power balancing strategies. Previously, we have presented the experimental implementation of the wind energy conversion system. It enables to have similar power dynamics and characteristics as a real wind generator. The wind power emulator is used to provide the needed wind power profile. The fuel cell emulator and the electrolyzer emulator are used to provide the same electrical behavior as the real fuel cell.

In order to test the grid following strategy, the same fluctuant wind power profile is used during 150 seconds. The active power requirement from the microgrid is assumed to be P_{gc_ref} =600W. The experimental results are compared with the simulation results.

The DC-bus voltage is well regulated around 400V. Thanks to the energy storage systems, the active power, which is exchanged with the grid, is well regulated.

For the energy storage systems, when the generated wind power is more than 600W the electrolyzer is activated to absorb the power difference. When the generated wind power is less than 600W, the fuel cell is activated to compensate the power difference. Since the power dynamic of the fuel cells and the electrolzyer are limited by a low-pass filter with a 5s time constant. They are not able to filter the fast fluctuations of the wind power. Therefore, the super-capacitors supply or absorb the rest of the required power in order to respect the microgrid's power requirement ($P_{sour} = P_{gc\_ref}$ =600W). The grid active power is slightly less than the microgrid's requirement ($P_g < P_{gc\_ref}$ =600W) because different power losses in the filers and in the power converters are not taken into account in the system study.

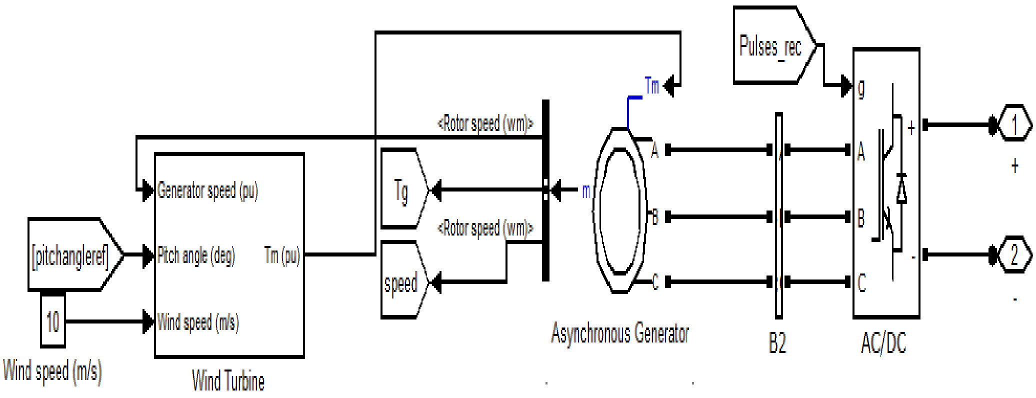


Fig 6: Simulation design of wind energy system

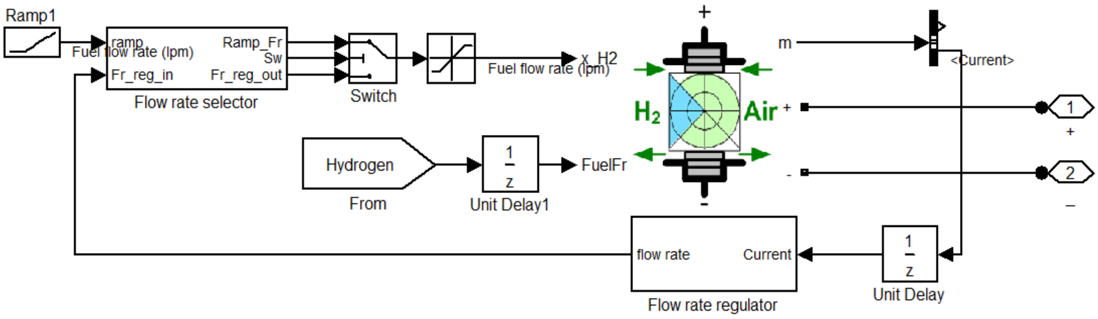


Fig 7: Simulation design of Fuel Cell

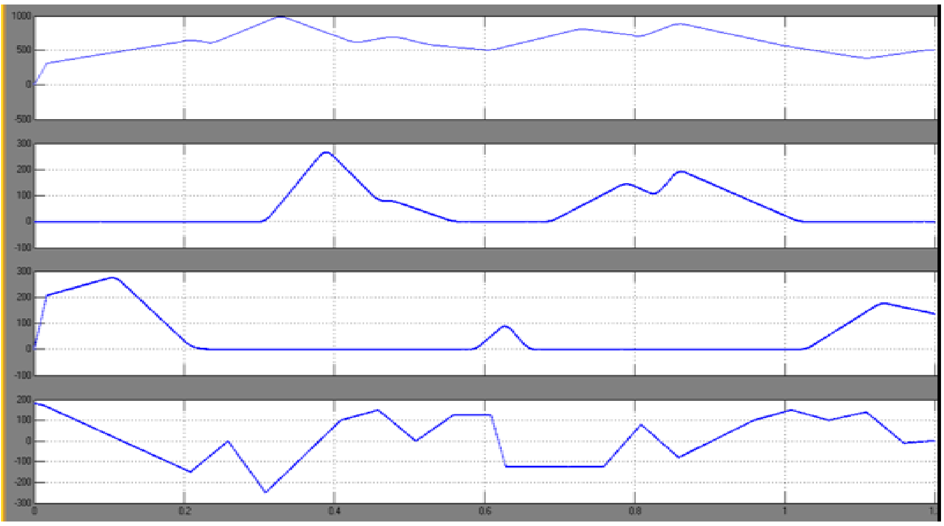


Figure 8: Wind Power, Electrolyzer power, Fuel cell Power, Super capacitor Power

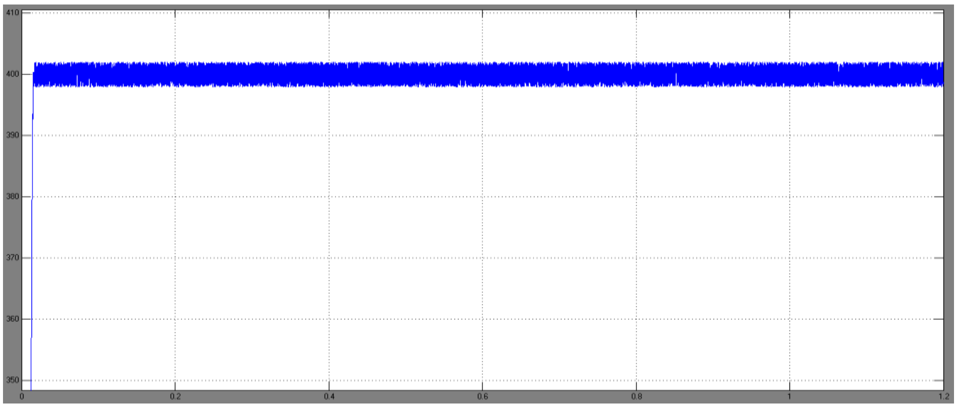


Fig 9: DC bus voltage of DC microgrid

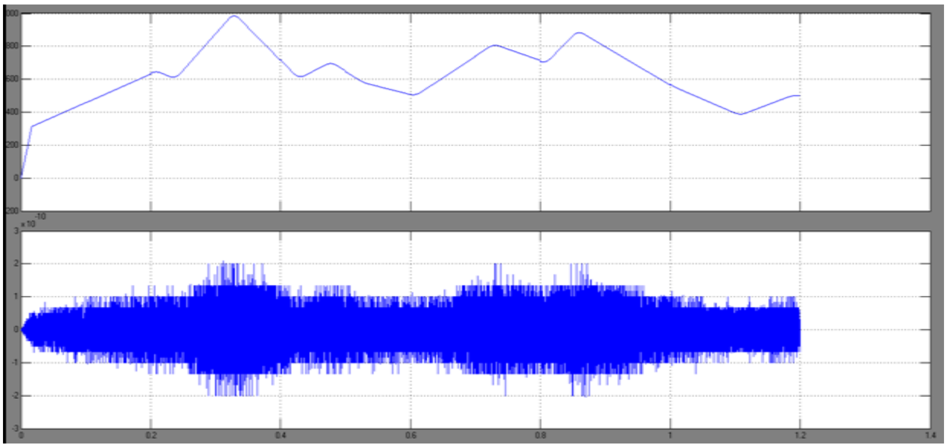


Figure 10: Active and Reactive power at bus terminals

VI.CONCLUSION

An integration of both wind power and fuel power generation systems joined with a dc microgrid has been proposed. The objective is to design an active wind generator, which can work like a classical power plant to provide ancillary services to the electrical system of the microgrid. The regulation of DC bus voltage is well achieved irrespective of dynamic behavior of wind, fuel and electrolyzer. The simulation design of proposed system is represented in section 5 and the performance characteristics are given. They are finally integrated together to form a wind/hydrogen/super-capacitors hybrid power system. The study consists of the design of the power balancing and energy management strategies. Several tests have been done to compare the performances with simulations and experiences. The power fluctuation of the hybrid system has been reduced as compared to that of each individual system and it has been completely suppressed using the FC system.

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