NOVEL COMBINATION OF A HYDROGEN STORAGE PROCESS FUEL CELL "MYRTE" WITH AN ADSORPTION CHILLER

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Abstract - This paper presents a recovery solution of thermal energy produced by a PEM fuel cell by the mean of anadsorption cooling process for cogeneration purposes. The fuel cell considered is part of the MYRTE platform, a real-scale demonstrator of the University of Corsica that aims to produce and store photovoltaic electricity through hydrogen. The heat produced by the fuel cell is transferred to a cooling circuit of glycol-water that can reach a temperature of 70°C for a nominal electric power of 210 Kw. The recovery is performed by a 7Kw SorTech ACS 08 Silica-gel/water adsorption chiller capable of producing cold water at 10° C, when being fueled by hot fluid with a temperature range of 55- 75 ° C.

Index Terms - Adsorption cooling, Cogeneration, Fuel Cell, Heat recovery, MYRTE Platform

I. INTRODUCTION

Renewable energies have emerged as an alternative to fossil fuels, following the increase of energy consumption, greenhouse gas emissions, electricity peak demands and energy costs [1]. In an insular context such as Corsica, where the electricity grid must largely be fed by small independent systems (thermal power plants) of the continental metropolis, inevitably leading to an increase in electricity prices and fluctuations governed by the gap between production and consumption.

Figure 1. View on the platform MYRTE (Ajaccio, Corsica)

The MYRTE platform was born from a collaboration between the University of Corsica Pasquale Paoli, the industrialist Areva and the Commissariat for Atomic Energy and Alternative Energies (CEA). It was inaugurated in 2012 at Ajaccio, in the Corsican island (France). The platform of almost one hectare presented in figure 1 is composed of a field of photovoltaic panels with a total surface of 3700 m², a unit of electrolysers producing H_2 with a flow rate of 40 Nm^3h^{-1}, storage tanks of O_2 and H_2 at 35 bars, with a capacity of 28 m^3, a fuel cell unit with a nominal power of 210 kW, a thermal loss management system with a capacity of 800 kWh / day, and different tools of control and electrical conversion [2]. The use of waste heat has become an increasingly urgent task for modern industries operating in sectors such as chemicals, steel, metallurgy or power generation. The recycling of thermal waste from these industrial processes could not only reduce the cost of energy but also reduce heat emissions in the environment [3]. The heat produced by the fuel cell and the electrolyser can be upgraded by supplying hot water to adjacent buildings, by heating them or even produce cold for a tri-generation system. Among the recovery options of MYRTE fuel cell, the adsorption cooling technology can operate at temperatures starting at 55° C. To study the combination of these two processes for the cooling of adjacent buildings, the operation of each unit is detailed, namely MYRTE heat management System and SorTech adsorption chiller.

II. HEAT MANAGEMENT SYSTEM

The heat management system of recovery and storage allows the cooling of the electrolyser and fuel cell units. It enables the heat produced by these units to be stored for reuse in a secondary network, for example, the heating circuit of a building, in order to improve the efficiency of the hydrogen chain. The heat management subsystem includes a dry cooler, a recovery heat exchanger, a mantle heat exchanger and a heat storage of 14 m^3 capable of storing 800 kWh/day. The system can be in different states as shown in Figure 2:

A. Cooling mode with storage + dry cooler
If the storage is not full,
B. Cooling mode without storage + dry cooler
Occurs if the storage is full, or if return temperature of the water from the fuel cell and electrolyser is lower that the set point.
C. Automatic discharge without heat recovery
The system allows the removal of heat previously stored by using the dry cooler and the storage tank without passing through the process heat exchanger.
D. Heat recovery mode
If the cooling mode is no longer required, this mode

makes it possible to upgrade the energy stored in the storage tank through the recovery heat exchanger.

E. Shutdown state and manual mode

The system is equipped with a switch for general shutdown and tilt to the manual functioning.

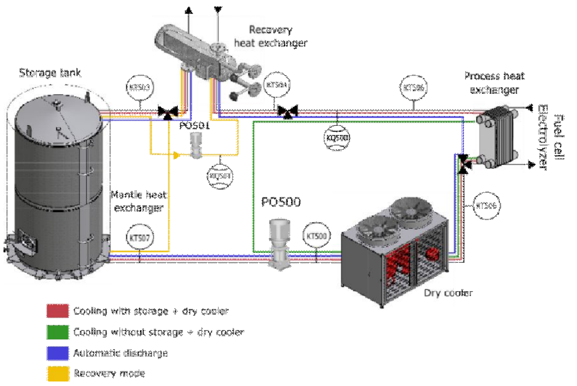

Figure 2. Representative diagram of MYRTE heat management system

III. SORTECH ADSORPTION CHILLER

In 2008, SorTech AG (Germany) developed a thermally driven ACS 08, a small-scale single effect, silica-gel/water adsorption chiller with nominal cooling capacity of 7.5 kW [4]. Its schematic diagram is presented in figure 3.

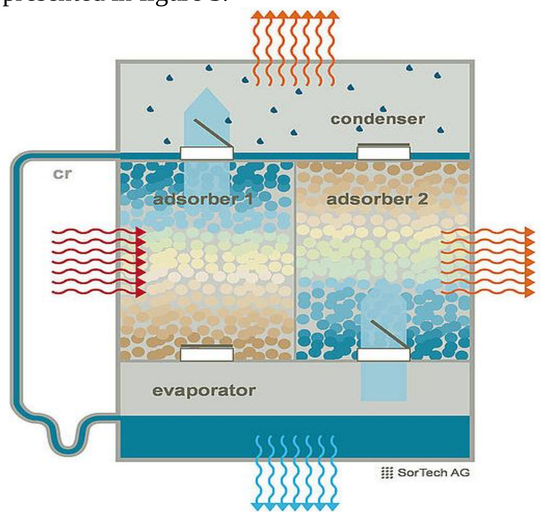

Figure 3. Schematic diagram of the SorTech ACS 08

Adsorption is based on a physical or chemical reaction process, resulting from the interaction between an adsorbent(solid) and an adsorbate (gas), as illustrated in figure 4. It is an exothermic process due to the liquid-gas phase change. The SorTechmachine operates cyclically. Two containers act, in turn, as an adsorber and desorber. In the first period, the first adsorbent is used to produce cold, while the other is traversed by hot water, and thus regenerated. In the second period, when the first adsorbent is saturated, it is replaced by the second and is then itself regenerated. The high pressure desorbed water vapor goes into a condenser where it gives away its calories to the ambient, the liquid water is then expended through a U-tube before reaching the evaporator at a low pressure and temperature. The evaporation process consumes the surrounding heat and thus produces cold. The liquid refrigerant then is directed toward the adsorber for a new cycle.

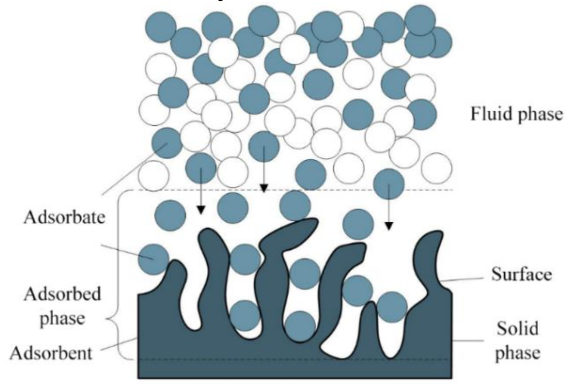

Figure 4. Schematic representation of adsorption [5]

This process is governed for several valves allowing the proper functioning of the chiller.

IV. COMBINATION OF THE PROCESSES

The study of the fuel cell heat recovery was fulfilled in 3 stages; mathematical modelling, d; mathematical modelling, dynamic simulation and experimental validation.

A. Mathematical modelling

To describe mathematically the thermal functioning of each unit of the combined processes, the lumped parameter model is used, based on the energy balance equations. Theses equations allow us to calculate the mean temperature inside the units of both the heat management system and the adsorption chiller, by taking into account the different entering and outgoing heat flows. Using this method, the temperatures of the different components of the heat management system are calculated: the two sides of the different heat exchangers, the pipelines and the storage tank. The latter was modelled using two methods: lumped parameter model and discretization model. The adsorption chiller is separated into four control volumes: the adsorber and desorber are characterized by the adsorption kinetics, the adsorption isotherm andthe energetic balance. The condenser and evaporator are described by energy balance equations and mass balance equation for the overall refrigerant mass calculation.

B. Dynamic simulation

The first-degree differential equations mentioned in the previous section are implemented into MATLAB – SIMULINK, a robust dynamic simulation tool that uses blocks and signals to solve complex equations.

- The simulation includes a system control that aims to manage the functioning modes of each process:

- The selection of the heat management system operation mode, based on electric and cooling needs.
- The cycle time allocation of the adsorption chiller based on analogic signals and the chilled water heat flow (Qev), and shown in Figure 5.

The simulation parameters were collected from the manufacturer documentation and the literature data.

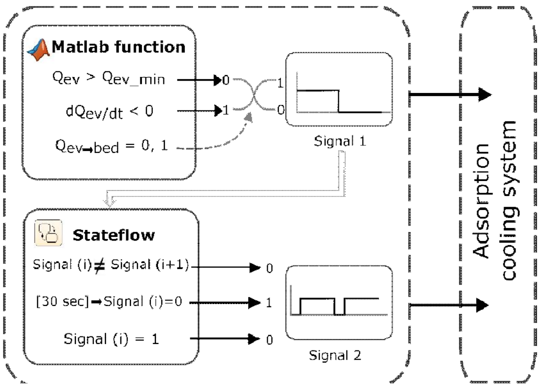

Figure 5. Distributed control strategy for the chiller simulation

C. Experimental validation

To evaluate the accuracy of the simulation, individual experiments on each process were conducted. The heat management system was tested for the charge and discharge of the $14m^3$ storage tank. The fuel cell operated for 11 hours at its nominal power, the next three months, the storage tank was isolated from the rest of the heat management system to study its thermal stratification. The experiments on the adsorption chiller were achieved at the University of Loraine, in Nancy (France) on a platform named ENERBAT. A tri-generation process, supplemented by a renewable energy source, coupled with a wooden construction. The tri-generation consists of gas cogeneration coupled to a SorTech adsorption refrigeration machine (see figure 6). It is supplied primarily by thermal solar panels arranged on the roof and a natural gas co-generator in case of low solar radiance [6].

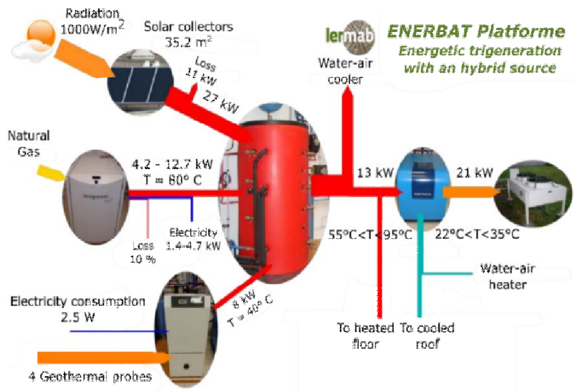

Figure 6. Sankey diagram of the ENERBAT platform

An optimization tool (PSO, Particle Swarm Optimization) available in MATLAB was used to fit the calculated parameters with the experiments, and statistical indicators such as the Mean Absolute Error (MEA) and Normalized Root Mean Square Error (nRMSE). The results obtained showed a good accuracy with the experimental data.The two major simulation blocks are then combined to predict numerically the cooling effect of the adsorption chiller when fueled with a constant water flow provided by the heat management system. The fusion point occurs at the recovery heat exchanger mentioned previously, where the hot fluid is the water glycol and the cold fluid is the regeneration water of the chiller. Adding thermal solar panels to heat the incoming water is also investigated.

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