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Feasibility study of hybrid fuel cell and geothermal heat pump used for air conditioning in Algeria

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ABSTRACT

Hybrid Energy System (HES) is mainly based on proton exchange membrane fuel cell (PEMFC) technology, which is supplied by a fuel reforming process for hydrogen production, starting from natural gas. The exhaust heat from the PEMFC is evacuated to a thermal storage tank (TST) mixed with water provided by geothermal source, The bath (Hammam) Sidi Aïssa 47 °C, TST hot water maintained to 47 °C is used in a fan coil for canteen heating in Si Ben Salah School located in Saïda (NW of Algeria). Cooling is assured by the air conditioning sub-system made of a fan coil and heat pump using cool water tank. The experimental analysis of the air conditioning device is done for canteen application for cooling and heating modes. The feasibility study shows that using the geothermal sources located in Northern Algeria and low temperature PEMFC for air conditioning is a promising solution.

1. Introduction

Fuel cell technology is one among the most promising devices for delivering clean and efficient power for automotive and stationary applications [1,2]. The proton exchange membrane fuel cell (PEMFC), has high efficiency, its reliability and its modular structure makes it suitable for many applications, with excellent performance at partial load and without atmospheric and acoustic emissions [3,4].

In order to integrate a PEMFC into a stationary application, a fuel reformer, a fuel cell stack with appropriate water-air, thermal management sub-systems, an inverter, a power conditioner and a battery pack are necessary. Natural gas appears as the best fuel for hydrogen-rich gas production due to its favourable composition from lower molecular weight compounds [5–7]. The main technology for natural gas fuel reforming for PEMFC application is steam reforming [8]. For simplicity, the natural gas is represented by pure methane, CH_4 [9]. Algeria has proven natural gas reserves of 4.5 trillion cubic metres, the largest natural gas field is located in Hassi R'mel region; its reserves represent half of all the Algerian proven reserves [10,11], Arzew and Skikda are also the shipping points for liquefied natural gas [12].

The presence of commercial and residential fuel cell systems for the generation of electricity and heat offer to the electric power industry is a great opportunity to increase their competitive position [13], while contributing to reduce environmental emissions. The vast variety of alternative energy generation methods, like geothermal, fuel cells, solar cells and wind turbines, yield opportunities for development of new

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hybrid energy systems that will be unique for the geographical environment of a specific region. Hybrid Energy Systems Study (HESS) done by Rochester Public Utilities and the University of Minnesota Rochester [14] was a research study focusing on the systems level integration of alternative energy technologies. The primary emphasis was on the combination of a heat pump and low grade thermal storage system. Low grade heat is available from sources such as fuel cells, solar thermal or hybrid collectors, biomass conversion plants, etc. The study done [14] encompassed comparisons between typical geothermal wells and stored thermal energy as heat sources, heat pump operation in heating and cooling environments, and the control systems necessary for the functioning of a hybrid plant.

In Algeria, the air conditioning is very budget in terms of energy consumption. One solution is entirely appropriate: geothermal resources exploitation. First, emphasis must be put on controlling energy consumption by improving the thermal insulation. But the use of geothermal energy can allow going further because of its independence to the climatic conditions, its local availability and its environmental friendliness. Geothermal energy involves taking the energy from the aquifers to feed a house, using a system consisting of a fan coil and heat pump.

As part of a program devoted to the promotion of renewable energy in Algeria, the Ministry of Environment and the direction of the environment of Saïda city (NW Algeria) in collaboration with the company EURL AL SOLAR, have set up a geothermal air conditioning system in a primary schools of Si Ben Salah, located near a geothermal source "(Hammam) Sidi Aïssa" (47 °C). The aim of this paper is to study the feasibility to combine geothermal source with PEMFC sub-system (PEMFCS), in order to develop on-site independent Hybrid Energy System (HES) to be used in the geothermal wells located in Northern Algeria (Fig. 1) [15].

HES are powered by PEMFCS, supplied by hydrogen produced by steam reforming to provide air conditioning to a canteen located in Saïda (435 km from Algiers). The air/water heat pump and fan coil sub-systems performance are examined experimentally for cooling and heating modes, the sizing of the PEMFCS and the quantity of CH_4 consumed is estimated theoretically. The data used in this study is provided by the solar potential Department belonging to the Center of Development of Renewable Energies (Algiers, Algeria).

2. Description of the system

HES is based on several sub-systems, PEMFCS, two tanks for cooling and heating modes, fan coil and air/water heat pump.

Fig. 2 represents the schematic description of studied HES; this system is made of two sub-systems; PEMFC sub-system (PEMFCS) and air conditioning sub-system.

PEMFCS is modelled as a sub-system with methane as input parameter and electricity and thermal energy as output parameters. PEMFCS is cooled by the outlet hot water recovered by the geothermal source flat plate heat exchanger as shown in Fig. 2.

Empirical relations will be used to relate the fuel input to the electric and thermal energy outputs. The thermal to electric output ratios of the fuel cell sub-system is given by [13]:

$$r_{TE} = 0.6801 \qquad \text{for PLR} < 0.05 \tag{1}$$

$$r_{TE} = 1.0785 \times PLR^4 - 1.9739 \times PLR^3 + 1.5005 \times PLR^2 - 0.2817 \times PLR + 0.6838 \qquad \text{for PLR} > 0.05 \tag{2}$$

The complete PEMFCS electric efficiency is given by:

For PLR < 0.05

$$\eta_{electrical} = 0.2716 \tag{3}$$

For PLR > 0.05

$$\eta_{electrical} = 0.9033 \times PLR^5 - 2.9996 \times PLR^4 + 3.6503 \times PLR^3 - 2.0704 \times PLR^2 + 0.4623 \times PLR + 0.3747 \tag{4}$$

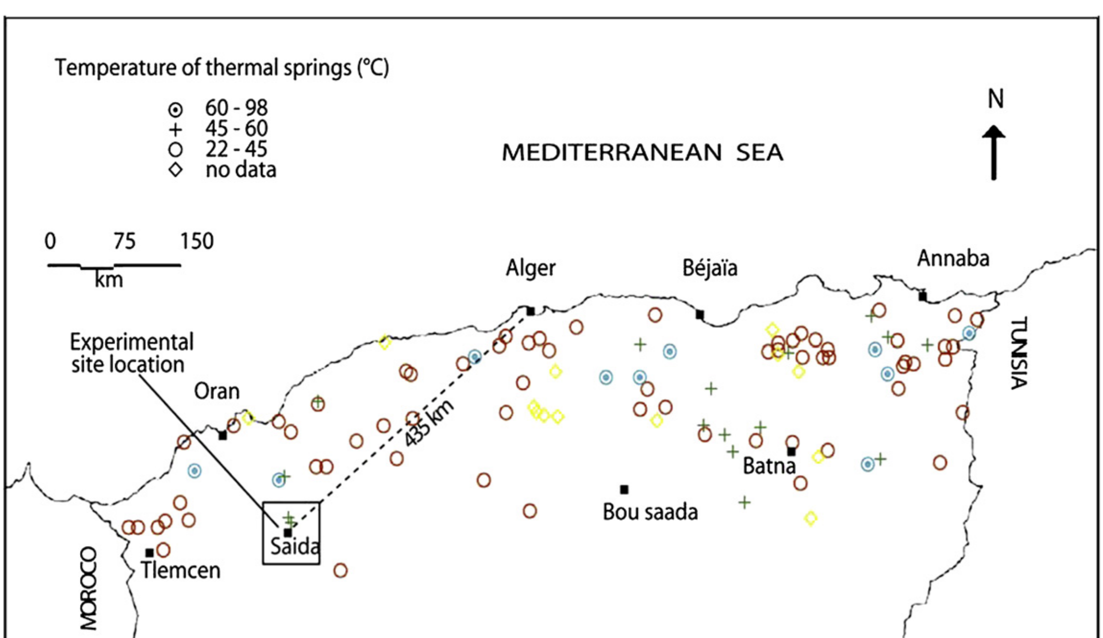

Fig. 1 – Map of Algeria showing the site of the air conditioning geothermal installation location in Saïda.