Worldwilde Uses of CHP Systems Identification and an Economic Viability Study of the Installations of CHP Systems in a Brazilian Hospital

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***Abstract*—This paper aims to identify successful cases where Fuel Cell Combined Heat and Power systems (CHP) are used around the world and verify the economic viability of the installation of fuel cell systems for cogeneration in the hospital Polydoro Ernani de São Tiago, located in Florianopolis, Brazil. It was found that large cogeneration systems are indeed existent besides of the use of polymer electrolyte fuel cells (PEMFC) for domestic applications. Japan is an example where CHP are largely used, however in Brazil, where the hydraulic energy is abundant; FC is yet to be more present in the energy generation scenario even though its efficiency is improved when the generation of heat and electricity are combined. A research to find out the electrical and thermal needs of the hospital unit was carried out. In order to supply the unit's needs, three fuel cell systems were analyzed, and the energy generated by three hypothetical systems were priced considering the capital investment in each of these systems as well as its operating costs, based only on their fuel demand. The cost per kWh obtained from each of the three proposed systems was compared with the kWh currently paid by the hospital to the distributor. From this comparison it was found that fuel cell systems are becoming increasingly competitive mainly due to the increase in the cost of energy supplied by the distributor.**

***Index Terms*—fuel cells, cogeneration, energy costs**

I. Introduction

In cases where thermal and electrical energy are used, cogeneration can be an option for using fuel in a more efficient way and consequently reducing costs. Thermal energy is captured from the fuel cell exhaust allowing for applications in edificial heating and cooling processes. Due to this feature, fuel cells can achieve an overall efficiency of 90% - 95%. Such high efficiency has attracted many countries to invest in fuel cell technology.

In this case, the literature has shown that for many applications the SOFC (solid oxide fuel cell) systems have been widely used specially for stationary uses in different scenarios such as power units [1], office buildings and facilities [2]. Such systems can operate at very high temperatures which allow the integration with CHP (combined heat and power) systems for even higher efficiencies around 85% for a system fueled with natural gas [1]. Studies have shown the opportunity for trigeneration as well, allowing to incorporate CCHP systems for cooling purposes [3].

Another example of utilization of CHP Fuel Cell Systems can be found in the study presented by Chen and Ni [3], in which the thermal energy is captured from the fuel cell exhaust allowing for applications in edificial heating and cooling processes. Cogeneration provides for a dual supply of energy; whether it primarily be electricity or heat. Systems can be altered to meet the needs of the stationary application. Additionally, Chen and Ni [3] affirm that the cost of incorporating cogeneration to fuel cell systems is relatively inexpensive. The major ancillary component required is a heat exchanger that uses the exhaust gas from the fuel cell to heat water or air. Trigeneration applications have been explored. One study suggests the utilization of thermally induced chillers. The chillers would supplement a buildings need for chilled air; whether it be during the summer months, or for freezer [3]. This paper, however, will focus on cogeneration applications.

In 2009, Panasonic launched in Japan a cogeneration system using fuel cells named “ene-farm”. That was the first fuel cell system for domestic applications to be commercialized. Since then, the company has improved the technology and released new models in 2013 and 2015. When compared to the first model launched in 2009, great improvement has been made in the nominal power generation efficiency and the lifespan of the product. The

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increase in the product demand, new technological advances and simpler structure design contribute to the reduction in costs to the customer. Other parameters also had a big impact on the success of the product as subsidy by the Japanese government, free technical support (10 years) and gas companies being the seller of the product [4].

Currently, Connecticut (US) has several on-going projects. The government granted US$3 million to a project of a microgrid that includes a fuel cell of 400KW for a police station, fire fighters and a secondary schools. The purpose of the project is to increase the reliability of the electric grid during extreme weather conditions. Hospitals, banks, data base centers and companies that depend on telecommunication are using fuel cells as a reliable source of energy [5].

In Europe (Spain, Germany, Italy, UK, Holland, Denmark, Belgium, Ireland, French, Austria, Luxembourg and Slovenia), the project “ene.field” will install 1000 domestic fuel cells for electricity and heat generation, which will represent an increase in the commercialization of fuel cell technology. With domestic applications corresponding to 27% of the total energy consumption in Europe, fuel cell technology is expected to reach 20% of the total energy production until 2020 [6].

II. Brazilian Scenario

A. Energy Matrix

As can be seen in the Fig. 1, Brazil has approximately 65% of its energy production from hydraulic sources. Brazilians renewable sources of energy represent 43.9% of all the energy consumption while worldwide only 14% of the all energy consumed comes from renewable source (in developed countries, it represents only 6%) [7].

Fuel cell energy generation has a small contribution to the total energy production and it was not represented in Fig. 1.

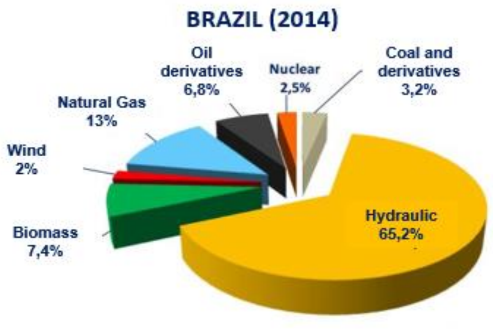


Figure 1. Brazilian energy matrix [7].

Even though renewable energy sources represent a large percentage of the Brazilian energy matrix, there is still a need for more incentives regarding fuel cell technology, which is something new and recent for Brazilian companies.

In 2005, the “Programa de Ciencia, Tecnologia e Inovacao para a Economia do Hidrogenio” (PROH2) was conceived with the intent to promote and develop fuel cell technology in the country with the long term goal of making Brazil an international competitor [8]. The main focus of the program was to invest in research and collaboration between companies and universities; particularly for stationary applications (50kW) and hydrogen production mainly using ethanol [9].

In the same year, Brazilian Ministry of Energy and Mines (MNE) created a Roadmap for Hydrogen Economy Structuring in Brazil, which the main purpose was to introduce hydrogen into the Brazilian energetic scenario through 2025, meaning, hydrogen generation from renewable energy sources, diversification of the Brazilian energy matrix and inclusion of Brazilian industry in the development of the hydrogen economy [10].

Since 2005, no other incentive program was launched until 2010, when the Centro de Gestão e Estudos Estratégicos (CGEE) released the document “Hidrogênio Energético no Brasil - Subsídios para políticas de competitividade: 2010-2025” which subsidizes political – institutional actions and proposals related to the scientific and technological development of hydrogen [11]. The main objective of this document was to facilitate the implementation of laws and incentives to improve the presence of fuel cells in the national scenario.

Despite these inscentive programs, currently the use of fuel cells in Brazil is not significant. There are important research groups and relevant scientific publications on the subject, but the use and commercialization of equipment for real applications is not a reality unlike other countries, as explained above.

B. Erasto Gaertner Hospital

Erasto Gaertner Hospital in Curitiba (Brazil) is one of the most important oncology centers in Brazil. The high demand for electricity and heat of the Hospital was once supplied by conventional sources of energy production with shale oil as fuel until being replaced by fuel cells as source of energy for vapor and hot water generation [12].

The PC 25C fuel cell, manufactured by International Fuel Cell (IFC), was the model chosen for the application above mentioned. It produces 200kW of electricity and 200kW of heat applied to cogeneration [12]. The purchase of the fuel cell was not only intended to supply the energetic needs of the hospital but also to be a research and development opportunity of technology in the country [12].

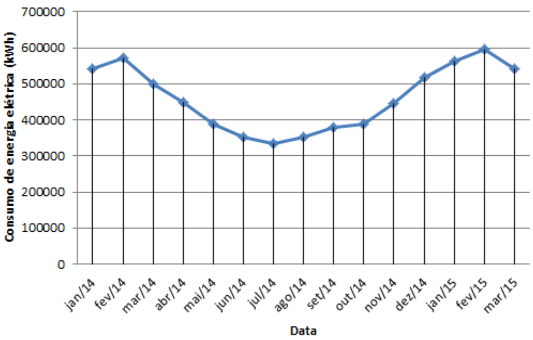
III. Case Study: Sao Tiago Polydoro Ernani Hospital

A case study was conducted to find out possible fuel cells systems that could supply the thermal and electrical energy demand of Sao Tiago Polydoro Ernani Hospital (Florianopolis, Brazil).

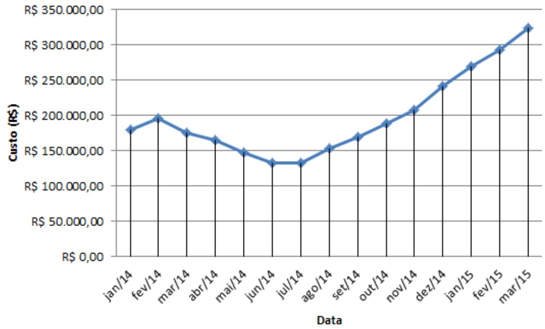
The hospital power plant is designed to generate electricity and vapor for water heating for showering and sterilization of equipment. The hospital has an electric boiler and two boilers that use diesel as fuel. In case of failure of energy supply from the municipality, the hospital uses two diesel generators to supply the energy needed to keep the hospital functioning. Usually only the newest diesel boiler (Fig. 2) operates. The two boilers diesel are horizontal water tube with steam generation capacity of 2,000 kg / h each.

Figure 2. Diesel boiler at the power plant of Sao Tiago Polydoro Ernani Hospital.

Fig. 3a shows the energy consumption of the hospital from January of 2014 to March of 2015. It can be seen that the average energy consumption was 46124.60KWh. Fig. 3b shows the cost of the electricity consumed by the hospital.



(a)



(b)

Figure 3. Electrical energy consumption (a) and cost (b) of Professor Polydoro Ernani de São Tiago Hospital.

It is seen that the energy consumption was higher from January until March, which is the summer time in the Southern Hemisphere. The high consumption is due to the air conditioning usage. The cost represented in the Fig. 3b is not related only to the amount of energy consumed but also related to the electricity price and the price of the foreigner fuel at that month period. In addition to the electricity consumption, the hospital also consumes 21000L of diesel per month for vapor generation, as mentioned previously.

Despite those facts, two different types of fuel cells were studied, solid oxide fuel cell (SOFC) and phosphoric acid fuel cell (PAFC). Since there is no Brazilian fuel cell manufacturer, the figures considered in this study were taken in US dollars and converted to Brazilian Reais at the exchange rate of 1U$=3.00R$. Table I brings the costs of the fuel cell types above mentioned, however taxes, cost related to transportation and maintenance are not included.

TABLE I. COGENERATION SYSTEMS DESIGN AND COSTS

Fuel cell model	Eletric power (kW)	Thermal power (BTU/h)	Unity cost (R$)	Lifetime (h)	Qty	kW cost (R$/kWh)
PAFC: Purecell 200	200	925000	8689200	85848	1	0.51
PAFC: Purecell 400	440	1734000	45618300	85848	1	1.21
PAFC system	640	2659000	54307500	85848	2	0.99
SOFC: ES-5710	262.5	7118475	14175000	131400	2	0.41

Fuel cells are devices that convert chemical energy into electricity having water and heat as byproduct. Each fuel cell type has its peculiarity and application. Some technological challenges are still need to be overcome before fuel cells to be widespread used. Polymer electrolyte fuel cells use Platinum as catalyst, which makes the fuel cell still expensive.

Alkaline fuel cells have problems with CO_2 poisoning when using air as reactant. The operating temperature is a crucial parameter when the application is cogeneration. High temperature fuel cells have the ability to tolerate CO (poison) and fuel flexibility. [13]

For a feasibility study, as the one herein presented, we must firstly define which scenario are we intend to address. Meaning, fuel cells systems can be designed with the requirement of (i) to supply all the electricity demand or (ii) to supply the heat demand. This study is done focusing on the requirement (i), we want to use fuel cells to supply the critical electricity needed to run the hospital and the heat generated as byproduct will be used to supply its thermal demand.

Once the scenario is defined, we choose which fuel type will be adequate. In our case due to high operating temperature we chose to work with phosphoric acid fuel cell and solid oxide fuel cell.

We chose to use the fuel cell system to supply the electrical demand of 500kW, and use the residual heat to supply, as previous mentioned, the thermal demand. This choice would eliminate the necessity of two boilers and the residual heat would decrease the fuel consumption of the third boiler.

As for how the network fuel cell system connection, for systems with less than 2000 kW capacity, the operation is made independent of the grid. This recommendation is given due to the high cost of the control system for connection in parallel, plus the cost of switching equipment. Furthermore, the objective of the system is to supply the critical loads only, so that there is no operation condition in which the electricity generated will be arranged to the grid network, making unnecessary the investment in parallel system.

IV. Results

Results shown on Table II and Table III compares the costs of the proposed fuel cell system to the cost of the electricity supplied by the municipality. The peak time was considered between 18:30-21:30h.

TABLE II. Energy Production Costs

System	Capacity (kW)	Capital cost (R$/kW)	Operational cost (R$/kWh)	Total costs (R$/kWh)
PAFC	640	0.9884385	0.2099	1.20
SOFC	525	0.411	0.001008	0.41

TABLE III. Electrical Energy Cost (R$/kWh)

Peak time	Out of peak time	Produced by PAFC system	Produced by SOFC system
1.45	0.42	1.20	0.41

The costs for SOFC are slightly cheaper during out of peak time. This was possible only due to the recent increase of the electricity cost. According to the data from March 2014, if off peak time is considered, SOFC would not be viable. However, if considering only peak time, the three proposed systems will present cheaper costs than those charged by the municipality. The costs related to transportation and installation were not considered in this study.

V. Conclusion

Worldwide, fuel cells are already a reality for stationary, vehicle and portable applications. The reduction of the fabrication costs of fuel cell systems has caused big expectations toward its spread application; however more initiatives from the government are still needed. Unfortunately, due to the structure of the Brazilian energetic matrix, the fuel cell technology is not seen as a necessity in the short term. However, especially with the increase in the cost of electricity, there is an opportunity to substitute the current less efficient systems.

Investment and effort must be applied in research and development (R&D) of components, products and systems and its manufacturing process as well. As witnessed in other countries, action from the government must be taken to assist the fuel cell market so demand for fuel cell technology will be improved and its cost will be reduced.

In conclusion, it is clearly seen that the development and use of fuel cells represent a challenge for the Brazilian engineering community, that goes from the inclusion of the topic in the academic environment to the manufacturing process and companies that will make the components designed by local scientific community. It's crucial for the country to be parts of the hydrogen economy as an international supplier which would make the final price of the fuel cell system more attractive.

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