Trigeneration Systems with Fuel Cells

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Abstract

Trigeneration systems include those processes of production and simultaneous use of electricity, heat and cold, from a single fuel source. The simultaneous use of energy allows obtaining high levels of overall energy efficiency, lower emissions, security of supply, as well as lower losses and investments in networks.
The context of implementation of trigeneration ranges from low voltage distributed generation to the electric microgrid prototypes currently under research. In this last environment, the work is mainly focused in the following power generation technologies: Fuel Cells, Microturbines, Stirling Engines, Small Wind Turbines, and Photovoltaic plants.
This paper focuses on those research proposals that are currently being developed using fuel cells as base technology for trigeneration. The paper presents the different subsystems that are part of these power generation systems, as well as their most important characteristics and applications.

Key words: Microgrids Trigeneration, PEMFC, AFC, PAFC, MCFC, SOFC.

1. Introduction

Within the context of distributed generation, microgrids rely on emerging technologies, such as fuel cells, gas microturbines, Stirling engines, as well as technologies that make use of local renewable resources. On the other hand, a growing deployment of a variety of technologies that allow the effective use of waste heat for power generation is being noticed. This involves increasing the overall efficiency of the systems and a reduction in the costs of implementation.

Table 1 highlights the most relevant properties of the emerging power generation technologies. These are the technologies being considered in the implementation of microgrids.

TABLE 1. –Characteristics of technologies in CCHP systems

	FUEL CELLS	STIRLING ENGINES	MICROTURBINES
CAPACITY RANGE	5 kW – 2 MW	1 kW – 1,5 MW	15 – 300 kW
FUEL USED	Hydrogen and fuels cont. hydrocarbons	Any (gas, alcohol, butane, biogas)	Gas propane, distillate oils, biogas
ELECTRICAL EFFICIENCY (%)	37 – 60	~ 40	15 – 30
OVERALL EFFICIENCY (%)	85 – 90	65 – 85	60 – 85
POWER TO HEAT RATIO	0,8 – 1,1	1,2 – 1,7	1,2 – 1,7
OUTPUT HEAT TEMP.(ºC)	260 – 370	60 – 200	200 – 350
NOISE	Quiet	Fair	Fair
CO_2 EMISSIONS (kg/MWh)	430 – 490	672	720
NO_X EMISSIONS (kg/MWh)	0,005 – 0,010	0,23	0,1
AVAILABILITY (%)	90 – 95	N/A	98
PART LOAD PERFORMANCE	Good	Good	Fair
LIFE CYCLE (year)	10 – 20	10	10
AVERAGE COST INVESTMENT (5 kW)	2500 – 3500	1300 – 2000	900 – 1500
OPERATING & MAINTEN. COST (5 kW)	0,007 – 0,050	N/A	0,01 – 0,02

In this field, cogeneration is the most outstanding technique for simultaneous production of electricity and heat [1]. If, in addition, a process requires of cooling levels below the ambient temperature (cold air, cold water or ice), and the cooling is produced from the same energy source, then, the generation process is called trigeneration. The cooling can be done through processes of absorption or adsorption.

Figure 1 shows the process diagram of a trigeneration system used for a high electrical efficiency energy system.

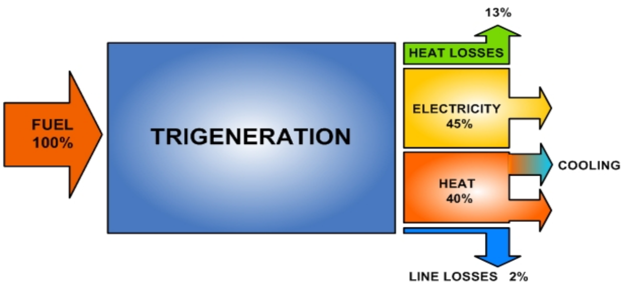

Fig 1. Schematic diagram of Trigeneration

2. Fuel cell technologies

Fuel cells develop electrochemical exothermic reactions, so the combined use of electricity and heat gives them a high overall efficiency, around 85% [2]. This thermal energy can be used for many purposes: within the fuel cell system, transferred outside to meet the demand of heating or cooling processes or released to the surrounding area without any application. In order to optimize the efficiency of these devices numerous investigations are being developed for the use of the thermal energy in water and air conditioning in homes, services and industrial facilities.

In Table 2, the technical and economic characteristics of different fuel cell technologies are shown, in relation to power generation [3].

TABLE 2. –Technical and economic characteristics of energy station power technologies

	LOW/MEDIUM TEMPERATURE FUEL CELL DESIGN			HIGH TEMPERATURE FUEL CELL DESIGN		HYDROGEN ENGINE GEN-SET
TECH. TYPE	PEMFC	AFC	PAFC	MCFC	SOFC	ICE/Generator
Typical electrical efficiency	30 – 50% (NG) 40 – 60% (H_2)	30 – 50% (NG) 50 – 60% (H_2)	37 – 42%	50 – 60%	45 – 60%	25 – 35%
Operating temperature	– 80 ºC	65 – 250 ºC	150 – 220 ºC	650 ºC	1000 ºC	> 1000 ºC
Waste heat grade	Low	Low-Medium	Medium	High	High	High
Waste heat use (typical)	Hot water, abs. cooling	Hot water, abs. cooling	Hot water, steam, process heat, abs. cooling	Steam, process heat, abs. cooling	Steam, process heat, abs. cooling	Steam, process heat, abs. cooling
Capital cost (current est.) ($/kW)	3000 – 4000	2500 – 3000	3000 – 4000	3000 – 4000	Pre-comm.	Early comm. No cost avail.
Capital cost (future goal) ($/kW)	400 – 600	250 – 500	1000 – 1500	< 1000	250 – 500	500
Hydrogen co-production source	Split reformer / Electrolyzer / Pipeline system	Split reformer / Electrolyzer / Pipeline system	Split reformer / Electrolyzer / Pipeline system	Anode tail gas	Anode tail gas	Split reformer / Electrolyzer / Pipeline system

3. Absorption cooling systems

Absorption cooling systems are based on the evaporation and condensation of a concentrated solution for producing cold. They can use any type of waste heat, steam, hot liquid or hot gas, providing cold for air conditioning or for low temperature processes. If the waste heat is a gas, a gas to water heat exchanger is needed within an intermediate circuit.

Table 3 highlights a summary of the most important properties of absorption cooling systems.

TABLE 3. –Absorption cooler´s characteristics

INDICES	NH_3 ABSORPTION	LiBr ABSORPTION	
EFFECT	SINGLE	SINGLE	DOUBLE
COOLING CAPACITY (kW)	20 – 2500	300 – 5000	300 – 5000
THERMAL COP	0,6 – 0,7	0,5 – 0,6	0,9 – 1,1
TEMPERATURE RANGE (ºC)	120 – 132	120 – 132	150 – 170
MACHINE COSTS (€/ton)	1250 to 1750	870 to 920	930 to 980

4. Trigeneration systems with PEMFC

This section presents some of the systems proposed for using fuel cells for trigeneration. In this abstract, the options based on PEMFC is presented briefly, while in the full paper these and other technologies will be analyzed in more detail.

Around 25% of primary energy consumption in some countries is intended for space heating and hot water supply. As the temperature levels necessary to meet these demands are relatively low, the PEMFC technology becomes as the most appropriate. Figure 2 shows the PEMFC technology working in trigeneration mode [4].

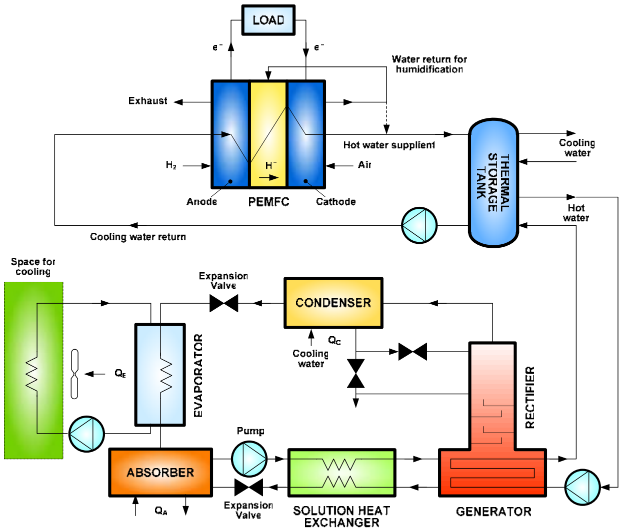

Fig.2. Schematic diagram of a PEMFC trigeneration system

5. Conclusions

This paper presents the most outstanding characteristics in trigeneration processes. This generation modality allows reaching high bench marks of global efficiency in the use of the fuel, by means of the use of the residual heat coming from the exothermic reaction of fuel cells.

Especially interesting are the systems able to use heat sources of low temperature (lower than 100 ºC), that is to say, able to take advantage of the residual heats of industrial origin or produced in cogeneration facilities.

Finally, from the operation point of view of the electrical system, these fuel cells can operate in two ways: constant power or with pursuit of the load. To this aspect, the high temperature fuel cells are better adjusted to the first operation way, while the low temperature fuel cells are more suitable for the second operation way, mainly because of outburst inferior times.

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