MOLTEN CARBONATE FUEL CELL: A NOVEL APPROACH TO POWERING LARGE TELECOMMUNICATIONS FACILITIES.

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ABSTRACT

Because of the increasing energy costs, problems associated with alternative energy back up sources and pollution in urban areas, Deutsche Telekom has started a quest for an alternative way of providing power to its large telecommunications sites. With the help of their service arm Deutsche Telekom Immobilien (DeTe Immobilien), they have focused their attention on fuel cells. The Molten Carbonate fuel cell was chosen as the favorite for deployment after carefully reviewing most of the existing technologies available in the market today. During September 2002 the first high temperature molten carbonate fuel cell started operating at a Deutsche Telekom site in Munich Germany. The 250kW cell, manufactured by MTU using patented technology from FuelCell Energy Inc., is an important source of electric power for this large central office site and represents a new way of thinking about back up power. The paper analyzes in detail the fuel cell operating mode, the impact that the fuel cell has in the design of the power plant and the in service experience gathered so far. The paper also explores some of the possibilities that this new technology offers in other applications.

MOLTEN CARBONATE FUEL CELL TECHNOLOGY

In general fuel cells are not too different from traditional batteries: There is an anode, cathode and electrolyte. However in a fuel cell the production of energy is linked to the introduction of “fuel” into the cell(s). In a molten carbonate fuel cell (MCFC), carbonate salts are the electrolyte. Heated to 650 °C (about 1,200 °F), the salts melt into a molten state that can conduct ions (CO_3^{--}), between cathode and anode. At the anode, hydrogen reacts with the ions to produce water, carbon dioxide, and electrons. The electrons travel through an external circuit to provide electrical power before they return to the cathode. At the cathode, oxygen from the air and carbon dioxide recycled from the anode react with the electrons to form CO_3^{--} ions that replenish the electrolyte and transfer current through the fuel cell.

Anode Reaction (-): $2H_2 + 2CO_3^{--} \rightarrow 2H_2O + 2CO_2 + 4e^-$

Cathode Reaction (+): $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{--}$

Total reaction: $2H_2 + O_2 \rightarrow 2H_2O$

High-temperature MCFCs can extract hydrogen from a variety of fuels using either an internal or external reformer.
The MTU “HotModule” fuel cell (Figure 3) uses natural gas (CH_4). The methane goes through a gas cleaner and humidifier where sulfur and other higher hydrocarbon are removed. After the cleaning process, the gas is then mixed with water and heated to about 400^oC (about 750^oF) before it is injected directly in the HotModule. This makes the hot module a so called Direct Fuel Cell (DFC). Inside the hot module, with the help of a catalyst the following reaction takes place:

Reforming Reaction: $CH_4 + 2H_2O + \text{Thermal Energy} \rightarrow CO_2 + 4H_2$

It is important to notice that because the reforming reaction occurs inside the fuel cell itself, the thermal energy necessary to produce hydrogen is absorbed from the waste thermal energy of the fuel cell thus making the process economical.

Advantages
One of the major advantages of fuel cells in general is the absence of polluting emissions. Like many other Telecom operators, Deutsche Telekom faces many environmental restrictions when employing traditional backup generators, especially in offices located in densely populated areas. In those cases, the cost of catalytic converters that must be installed on the generators to assure compliance with those restrictive emission standards is significant, thus making a fuel cell choice more attractive.
Other major advantages of the MCFC are linked to the absence of an external reformer.

The internal reforming offers many important advantages:

- Separate equipment for the reforming process is unnecessary. This enables a sustainable simplification of the system. From a telecommunications prospective, the absence of additional components that an external reformer would require, increases the MTBF thus making the cell more suitable for “reliable” power.
- The strong endothermic reforming reaction is thermally fed by the "waste" heat from the fuel cell. No additional energy has to be generated for that.
- "Waste" heat is changed into primary energy in the form of hydrogen.
- The reforming reaction removes heat from the fuel cell ("chemical cooling"). This enables a reduction of the parasitic cooling power.

The MCFCs are also less prone to carbon monoxide "poisoning" than lower temperature fuel cells, which makes coal-based fuels more attractive for this type of fuel cell. In actuality as CO_2 is used at the cathode, it is a welcome byproduct.
Another important advantage is that MCFCs work well with catalysts made of nickel, which is much less expensive than platinum. MCFCs exhibit up to 60 percent electrical efficiency. The fuel cell at the Munich site shows an electric efficiency of 52% that goes down to 48% once the energy for the auxiliary equipment is subtracted; the efficiency can rise to 80 percent if the waste heat is utilized for air conditioning and/or cogeneration.

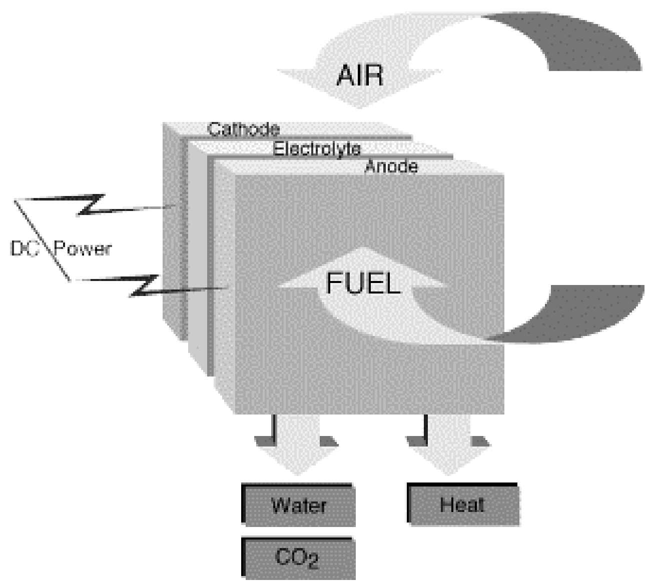

Figure 1: “Cell scheme”

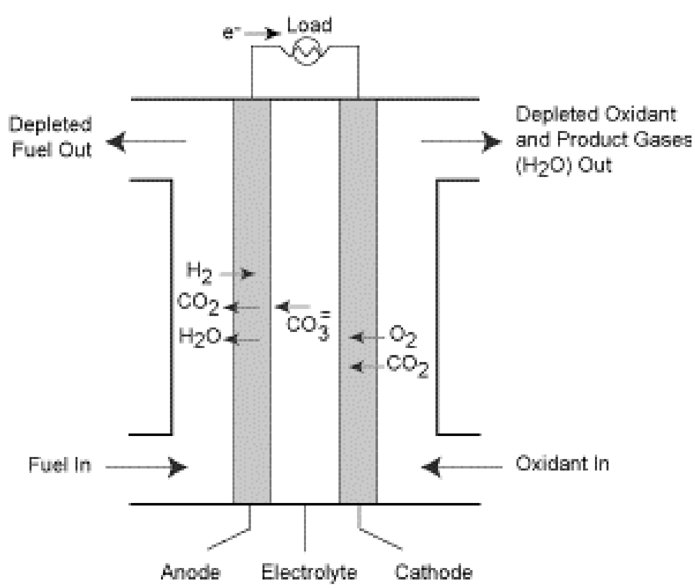

Figure 2: “Internal reactions”

Figure 3: "View of the HotModule and CH_4 Humidifier and Heater"

Table 1: "Technical Characteristics"

	Rated	**Observed Values on 2/2003 (*)**
Fuel	Natural gas (CH_4)	Natural gas (CH_4)
Power output (cell block)	270 kW	About 150kW
Net Power output	about 230 kW	About 150kW
Thermal output	170 kW	190 kW
Electrical efficiency (cell block)	56 %	44%
Electrical efficiency of the entire plant (grid)	about 48 %	41%
Overall utilization degree	> 90 %	N/A
Number of cells	342	342
Average Cell Voltage	840 mV	829 mV on average
Stack Temperature	650 °C (about 1,200 °F)	585 °C (about 1,085 °F)
Thermal utilization	two phases: process steam and/or heat	Heat
Service live (expected)	5 years – 44,000h	3,000h and counting
Electrical Energy Production (Expected)	10,000 MWh	450MWh
Weight	15 metric tons	N/A

(*) during the visit, the fuel cell was in a run in stage and was not fully utilized.

Disadvantages and Failure modes

Two major difficulties with molten carbonate technology puts it at a disadvantage compared to solid oxide cells. One is the complexity of working with a liquid electrolyte rather than a solid. The other derives from the chemical reaction inside a molten carbonate cell. Carbonate ions from the electrolyte are used up in the reactions at the anode, making it necessary to compensate by injecting carbon dioxide (CO_2) at the cathode. Also the nickel electrodes operate in a very hot and corrosive environment, thus their life is limited. The expected service life of the HotModule is 5 years or about 40,000 hours. After that time, the module must undergo a regeneration process, during which the electrodes are replaced.

While the high operating temperature has many advantages, it also constitutes a limiting factor in the employment of the technology.

As with all fuel cells, the MCFCs do not respond well to highly variable loads so precautions must be taken to provide energy to the load when it suddenly increases (through the use of an auxiliary battery or super capacitor), and to use the excess energy when it suddenly drops (pumping the energy into the utility grid for example).

As the fuel cell ages, the internal resistance of the stack increases lowering the output voltage. The health state of the stack can be obtained by monitoring the output voltage of the cell.

POWER PLANT DESIGN

During the design of the power plant, the DeTe Immobilien Engineers were facing the following scenario:

On the one hand they had an existing massive central office, with overall power of about two (2) MW, that serves about four millions residential and commercial customers with local, long distance, broadband and wireless services and were down time cannot be tolerated. On the other hand they had to implement the installation of a new technology whose dependability had not been proven yet. Redundancy had to be implemented at all levels. This is why the central office features a very large back up lead acid battery of about 100,000Ah.

Figure 4: Battery Room

The electrical layout of the power plant is shown on figure 4. From the figure the following elements can be identified:

1. The plant has 2 levels of DC voltages, 60VDC (usual in Europe for older installations) and 48VDC used for wireless services and newer wired equipment.
2. Main Rectifiers: Those are sized to provide the plant with the full capacity required by the plant;
3. Redundant rectifiers are used as part of the pilot program and constitute the backup for the fuel cell. They are set in stand-by and are activated only for maintenance and fuel cell failure;
4. DC/DC converters transform the electric energy from the Fuel Cell bus to a voltage level that is compatible with the telecom DC bus;

5. Inverters are used to “pump” the excess energy from the fuel cell to the utility grid;
6. Batteries are used to provide a full backup to the plant. In future installations, battery back up will be implemented only to overcome load spikes before the fuel cell can respond. This function could be performed also by super capacitors.

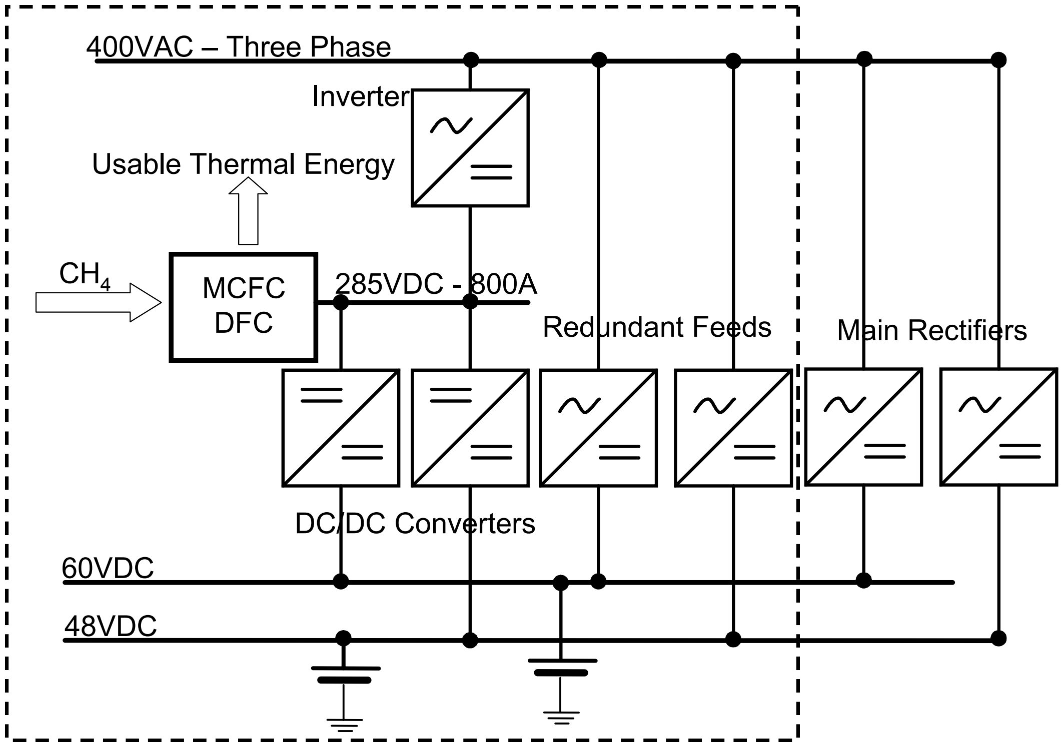

Figure 4: “Electrical Layout”

When employing fuel cells, what before used to be the main source of energy, the utility grid, becomes the redundant back-up. The fuel cell becomes the primary power generator that together with the DC/DC converters (Figure 5) feeds the load. Redundancy is achieved through the use of AC/DC converters that from the utility mains feed the load in case of fuel cell failure or maintenance.

Figure 5: 285VDC/60VDC DC/DC Converters 290kW

Being a pilot plant, the Munich central office is equipped with a single module; however future plants could be equipped with two or more modules to achieve true n+1 redundancy. It must be noticed that the redundant module could be fully utilized even when in a stand-by state to inject electric energy back into the utility grid thus generating revenues that can offset the installation and amortization costs.

CONCLUSIONS

Because of their technology limitations, Fuel cells that employ the Molten Carbonate technology seem to be well suited for applications with power requirements above 100kW. In that range they become more economically competitive. In telecommunications, this means central office. They can be seen as a good option in those cases were utility power is either not available or has poor quality and in those cases were the use of micro turbines has been contemplated.

It is important to notice that, if redundant fuel cells are used as backup, they do not represent an idle investment as they can be used to produce energy that can be sold to the local utility thus making the proposition more appealing.

After working with traditional batteries for many years, the authors felt very excited in working with this new technology. After visiting the Munich installation and researching the principles that make fuel cells work, it was easy to be carried away by the feeling that something new that is transforming the way we produce energy is in the works and that this transformation will bring incredible advantages. However we also learned that many road blocks are still present (cost is one of them but becoming less prominent) and that while scientists are quickly working to solve the different issues, it will take many years before the technology will become widely spread. Focusing on the telecommunication side for example, the introduction of fuel cells into the network requires the use of new untested plant typologies and elements. It will take some time before telecom companies will become confident enough to introduce these new elements deep into their networks. At any rate, unless there are major setbacks, that today cannot be foreseen, DeTe Immobilien is planning to install at least another 100 HotModules during the next ten years in the Deutsche Telekom network. Considering that there are about 740MW of installed backup power that uses traditional generators, this is not a huge number but certainly significant enough.

REFERENCES

www.fuelcells.org
www.fuellcellstoday.com