Hydrogen based emergency back-up system for telecommunication applications

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Abstract

This paper presents the design of a hydrogen based emergency back-up system for telecommunication applications, providing 5 kW power for 5 h. The system is composed of a water electrolysis unit, a hydrogen buffer tank, a metal hydride tank and a polymer electrolyte membrane fuel cell (PEMFC). In particular, the paper describes the design of the hydrogen generation and storage section and the various options that have been studied, based on technical and economical considerations of state-of-the-art hydrogen technologies. The water electrolyser produces $0.5 \, \mathrm{Nm^3} \, H_2$/h at 10 bar pressure. The 1 $\mathrm{m^3}$ conventional medium pressure tank has a capacity of approximately 6 $\mathrm{Nm^3} \, H_2$ and the metal hydride tank a capacity of 15 $\mathrm{Nm^3} \, H_2$. Particular attention is paid to the integration of the hydrogen storage and the fuel cell, with respect to optimizing heat exchange.
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1. Introduction

The idea of a hydrogen economy as a solution for a sustainable development has been making its way during the last three decades [1,2]. Recently, the first, small scale, "green" power systems based on fuel cells have been commercialized. Several concepts have been suggested for the development of hydrogen energy systems, where hydrogen takes up the role of the energy carrier or means of storage. Such systems generally consist of three sections: hydrogen generation, hydrogen storage and electricity production from hydrogen. The term regenerative fuel cell (RFC) is often used to describe the combination of a fuel generation device with a fuel cell to provide electricity when needed. The most common types of RFCs use hydrogen, generated via electrolysis of water, as the energy storage medium [3].

Hydrogen systems appear as strong contenders to replace batteries in the emergency back-up or uninterrupted power systems (UPS) market, especially in grid-connected applications where good quality, reliable power supply is required and where interruptions could last several hours. One such market is that of telecommunications and in particular providing emergency back-up for mobile phone repeater

stations that are connected to the electricity grid, but are in remote locations where interruptions are common. According to an IFC report [4], such applications could include fiber optic repeating stations, multiplexing stations, cellular towers, Internet backbone computing facilities. The power requirements for such telecommunication applications could range from 1 to 10 kW but can rise to 50 or even 100 kW for multi-purpose sites with many suppliers. Such telecommunication systems require an autonomy of 1–2 h according to Teledyne [5] or 24 h, according to IFC [4]. Conventional UPS, on the other hand, typically have an autonomy of 12 min at full load or 30 min at half load, while for longer interruptions an uninterruptible battery system is installed, consisting of a gen-set feeding the batteries.

Most studies on hydrogen systems for short- and long-term energy storage are related to renewable energy sources. Such hydrogen systems are also composed of an electrolyser, a hydrogen storage section and a fuel cell [6–9].

Some studies deal with the powering of remote communication stations based on hydrogen technologies integrated with renewable energy sources, in non-grid-connected applications. Agbossou et al. [10] described a system comprising a 10 kW wind turbine, a 1 kW photovoltaic array, a 1 $\mathrm{Nm^3}$/h H_2 electrolyser, a storage tank at 10 bar of 3.8 $\mathrm{m^3}$ water capacity (circa 125 kWh of stored energy based on HHV) and a 5 kW PEM fuel cell. A smaller system, consisting of a photovoltaic panel of 1.5 kW peak power, a 1 kW PEM

electrolyser producing hydrogen at 30 bar pressure, a metal hydride tank of 70 Nm^3 capacity and a polymer electrolyte membrane fuel cell (PEMFC) of 300 W power, is under development in the frame of a European project called FIRST [11].

2. Overall system design

The requirements for current telecommunications back-up systems have been established by taking into account the statistics of grid supply interruptions, that would affect grid-connected telecommunication relay stations. The prototype that will be realised provides 5 kW power for 5 h, through a PEM fuel cell, and copes with one major (up to 5 h) power interruption every 48 h, covering more than 99.6% of possible grid power failures, according to the statistics of grid supply interruptions in some European countries. The autonomy of the commercial system is readily adjustable, thanks to the modularity of the hydrogen storage design, that would allow the addition of extra hydrogen tanks.

Other important requirements for back-up power systems for telecommunications is high reliability and low maintenance costs. The aim of our system is to present a higher reliability than its main competitor, namely the diesel generator. The start-up failure probability of a diesel generator is greater than 10^{-2}. So, the objective of the HELPS system is to attain a start-up failure probability to the order of 10^{-3} or lower.

For the system to be used as an uninterruptible power supply, a battery will supply the load for approximately 3 min, until the fuel cell takes up the load. The battery should always remain fully charged. The duration of most electricity grid failures in Europe is lower than 3 min, which means that the fuel cell will rarely be operating.

A preliminary process flowsheet of the HELPS project is shown in Fig. 1 for a system composed of the following items:

a) an electrolyser producing 0.5 Nm^3/h H$_2$;
b) a hydrogen purification unit to bring the hydrogen purity at 99.999 vol.% required for the storage in a metal hydride tank;
c) a conventional hydrogen storage tank to supply the fuel cell at start-up, until the metal hydride tank is heated at the desired discharge temperature;
d) a metal hydride tank; and
e) a PEMFC working on H$_2$/air, with an output of 5 kW$_{electric}$ for 5 h.

The required magnitude of the hydrogen storage depends on the efficiency of the fuel cell. A compromise between efficiency and cost is necessary for the fuel cell, as it is for the water electrolyser. The fuel cell manufacturer has chosen a hydrogen consumption of 360 g/h (4.032 Nm^3/h) at nominal power output. Such a hydrogen consumption corresponds approximately to a 35% efficiency of the fuel cell subsystem, based on the high heating value (HHV) of hydrogen. It requires a storage of approximately 21 Nm^3 H$_2$ for 5 h.

At this stage, with no optimisation of the hydrogen storage distribution between metal hydride and conventional tank, we decided to keep the capacity of the metal hydride
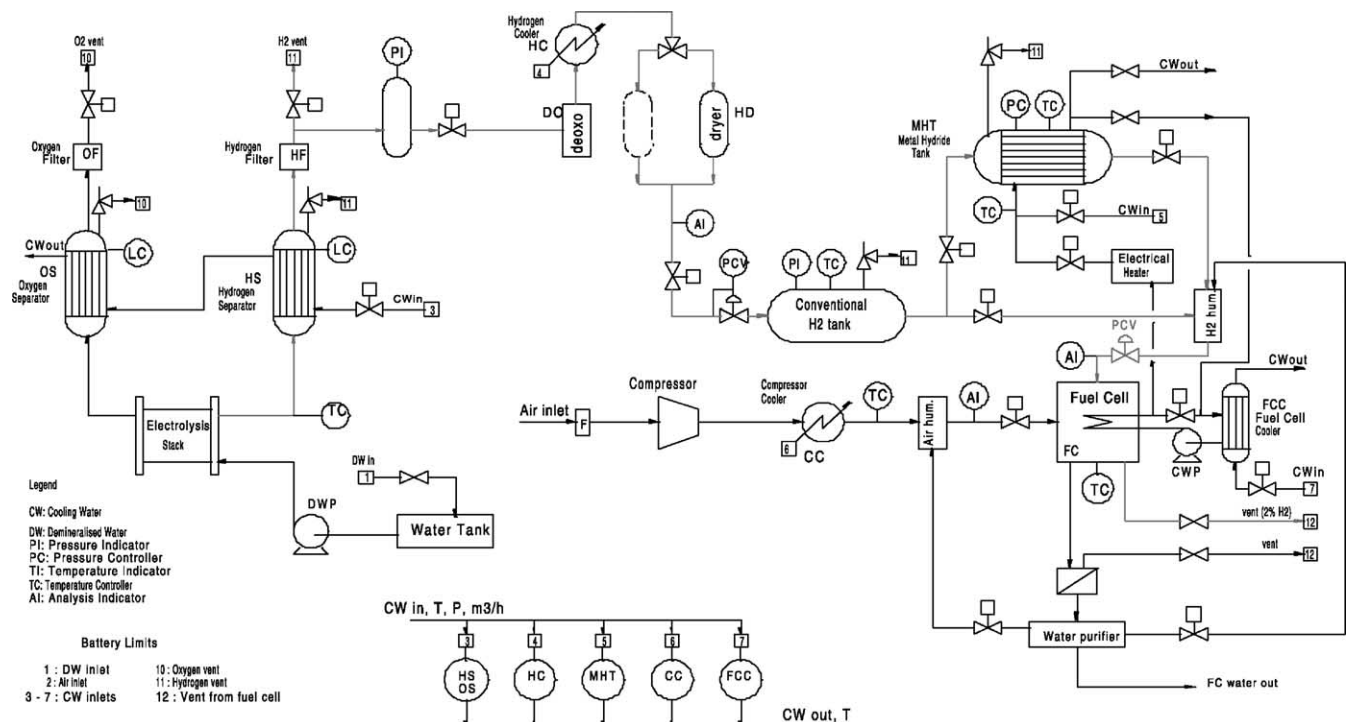

Fig. 1. Preliminary process flowsheet of the HELPS project.

tank at the budgeted value of 15 Nm^3 H$_2$, while adding a conventional tank of 1 m^3 water volume. If the conventional tank is filled at 10 bar and the pressure is not reduced below 3 bar (maximum working pressure of the fuel cell circa 2.5 bar), then 6.4 Nm^3 H$_2$ can be supplied by the 1 m^3 conventional tank, complementing the metal hydride tank.

The installation of an electrical heater (boiler) has been foreseen on the flowsheet in the water circuit for the heat exchange between the fuel cell and the metal hydride tank. A correct integration of the fuel cell and the metal hydride tank should allow to avoid heating, so that the efficiency of the system will not be reduced further.

Following the preliminary design of the system, three alternatives have been studied. The first option consisted of installing the conventional hydrogen storage tank between the electrolyser and the hydrogen purification section. In this configuration, the hydrogen stored in that tank (approximately 25% of the total hydrogen stored) can be supplied directly at circa 99.8 vol.% to the fuel cell. The energy spent for the humidification of the fuel cell stack will, therefore, be reduced. In addition, assuming that the purifying section typically consumes 8% of the hydrogen produced, the efficiency of the system will increase if 25% of the hydrogen produced short-circuits that section. This option is still under study, because its implementation implies that the hydrogen supply to the fuel cell will have a varying purity and humidity.

The second option consisted in replacing air by pure oxygen as supply for the fuel cell. The design of the system with a hydrogen/oxygen instead of a hydrogen/air fuel cell is schematically presented in Fig. 2. The advantages of repla-

cing the air compressor for the supply of the fuel cell by the storage of the oxygen produced by water electrolysis are discussed hereafter.

Using oxygen instead of air allows to either increase the efficiency of the fuel cell subsystem, or to decrease its cost. First of all, the compression work for the air supply can represent up to 12% of the consumption of the fuel cell subsystem. The investment cost of the air compressor would be counterbalanced by the investment cost of the oxygen storage. In the absence of nitrogen, the energy for the humidification of the oxidant can be greatly reduced, but this energy has not been taken into account in our study, because the humidification section depends on the detailed design of the fuel cell stack.

The efficiency of the fuel cell stack depends on several parameters such as working pressure, operating voltage, oxidant/fuel stoechiometry, but can easily attain 60%, based on the HHV of hydrogen, if oxygen is used. According to our calculations, replacing air with oxygen, would allow to increase the efficiency of the fuel cell subsystem from 35 to approximately 50%. As a consequence, the volume of stored hydrogen would be reduced from 21 to 14 Nm^3, while a storage of 7 Nm^3 of oxygen would be added. The total volume of both gases to be stored would be equal to the volume of hydrogen stored for a hydrogen/air fuel cell. If the volume of stored hydrogen decreases, the capacity of the electrolyser could also be reduced from 0.5 to 0.35 Nm^3/h H$_2$. The option of increasing the efficiency of the fuel cell subsystem by using oxygen, would decrease the investment cost of the hydrogen storage and water electrolyser.
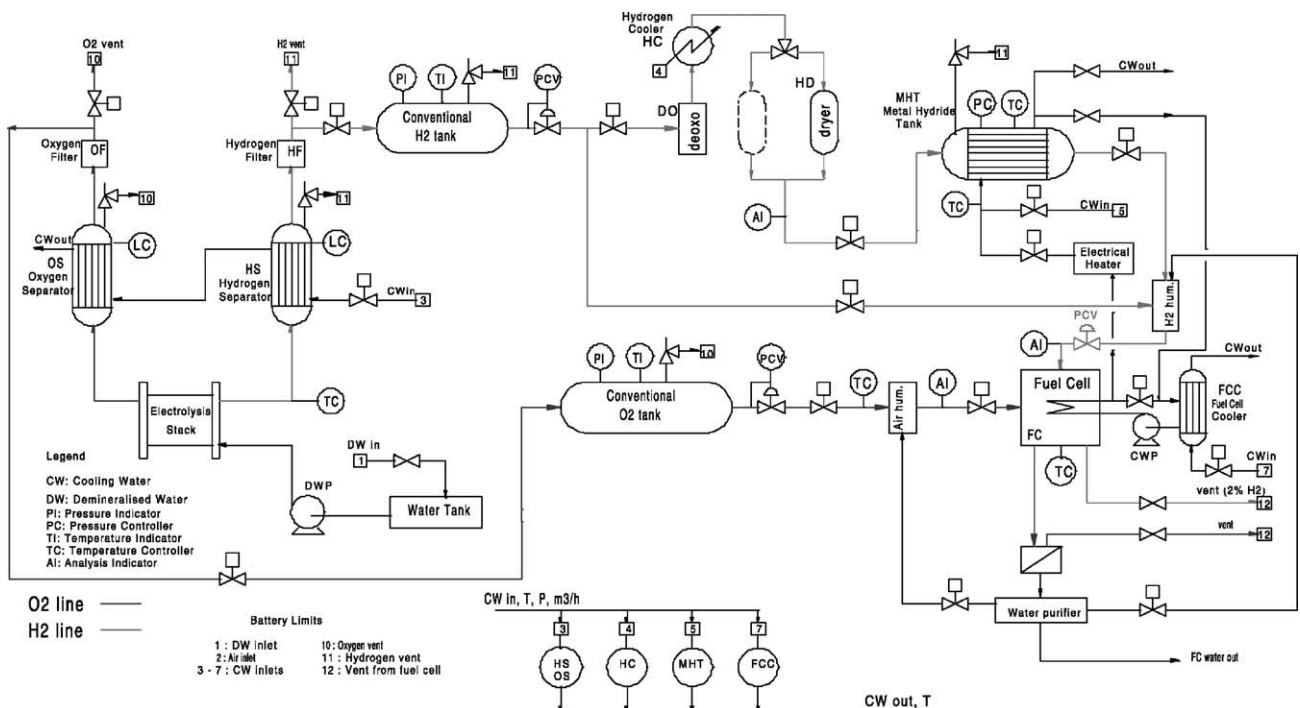

Fig. 2. Process flowsheet using oxygen instead of air in the fuel cell.

However, it is also possible to maintain the efficiency of the fuel cell subsystem at the same level for oxygen operation as with air operation. The hydrogen consumption would remain the same in both cases, but the cost of the fuel cell stack would be reduced, by choosing the appropriate operating conditions. In the frame of our project, this solution has been estimated as the most economical one.

The third option consisted in using air enriched with oxygen as oxidant supply to the fuel cell. A part of the oxygen produced by the electrolyser would be stored at the delivery pressure of the electrolyser. If the oxidant flow to the fuel cell contained 40 vol.% of oxygen for example, the system would keep a part of the benefits cited above, but the oxygen storage tank could be very small. So, the safety risks in the plant would be reduced with respect to a complete oxygen storage. This option was not studied in further detail, because the option of using oxygen seemed more promising.

3. Hydrogen generation

The major part of hydrogen is produced worldwide from fossil feedstocks, based on processes such as steam reforming and partial oxidation. Today, steam reforming is often considered as the uncontested generation step for a future hydrogen economy. So, the majority of studies on the efficiency and economics of fuel cells take into account different scenarios on the present and future price of hydrogen from different reforming systems [13,14]. However, the cost advantages of steam reforming only hold for large production volumes. For production rates up to $250 \, Nm^3/h \, H_2$, the investment cost of an electrolysis unit may be as low as 65% of the investment cost of a reforming plant [12]. The annual production costs depend on the respective price of natural gas and electricity at the particular site, which may be favorable for electrolysis. For example, hydrogen production from electrolysis may be advantageous at locations where excess nuclear power or cheap hydroelectric power is available. In the future, taking into account an increased use of renewable energy sources, water electrolysis may have an increased share in the worldwide production of hydrogen.

The purity of hydrogen generated by steam reforming differs considerably from the one generated by water electrolysis. The electrolysis provides hydrogen at a standard purity of 99.8 vol.%, containing only water vapour and traces of oxygen, so it can be directly supplied to a fuel cell without further purification. Reformed hydrogen may contain some traces of CO, a poison for the catalysts of PEMFC anodes, even after purification. A lot of research related to PEMFC stacks deals with the development of CO tolerant anodes [15], assuming that hydrogen is generated by steam reforming or other methods based on fossil fuels.

Another trend in research on PEMFCs, also based on the assumption that hydrogen is produced by steam reforming, is the study of stacks operating on air as oxidant, instead of oxygen. Commercial products are supposed to operate on air [16,17], even if the efficiency of the system is much lower than when pure oxygen is used, because oxygen is not available at a reasonable price. An advantage of water electrolysis, however, is that oxygen is produced simultaneously with hydrogen, and can be stored at low cost for the supply of the fuel cell. Interestingly, there are also studies on the development of PEMFCs operating on hydrogen/oxygen, where hydrogen mixtures containing CO and CO_2 have been used as fuel [18]. The fuel simulates a product of reforming, but the origin of oxygen was not precised.

For the in situ production of small quantities of hydrogen, as in the present application, water electrolysis is the only commercially available method. To our knowledge, there are less than 20 manufacturers of industrial water electrolysers worldwide.

Industrial electrolysers generally operate in alkaline medium, often a 30 wt.% KOH solution, at a temperature range of 60–80 °C. They employ steel or nickel-based electrodes and polysulphone membranes instead of the old asbestos diaphragms. The operating pressure varies from atmospheric to 5 bar pressure for conventional electrolysers and from 10 to 30 bar pressure for advanced electrolysers. Pressurised operation of the electrolyser is a very elegant way to produce hydrogen at pressures suitable for storage. The additional energy required is very small, approximately 30 mV per cell and per decade of pressure increase, which represents 1–2% of extra power consumption.

In order to lower the energy consumption by reducing the cathodic overpotential, several studies have focused on the development of active cathodes for the hydrogen evolution reaction (HER) [19–23]. A protective overvoltage is generally applied at the electrolysis stack when the plant is in stand-by mode, to protect the cathode from corrosion. Much effort has been concentrated on the development of corrosion-resistant cathodes for intermittent operation and especially for long period interruptions [19,24,25]. Recently, a lot of attention has also been directed to developing anodes for the oxygen evolution reaction (OER) [20]. Other studies have been dedicated to the development of membranes for advanced alkaline electrolysis [26]. The membranes must show low electrical resistance, low gas permeability, high mechanical strength and high chemical stability.

The use of a polymeric proton exchange membrane (PEM) was first proposed by General Electric for fuel cells, and later for electrolysers [27]. The Membrel technology, based on PEM water electrolysis, was developed by ABB, Switzerland. The long-term behaviour of 100 kW PEM electrolyser plants showed that the Nafion membrane was the weakest part of the electrolyser, leading to problems with excessive levels of hydrogen in the oxygen product [27]. Several studies were dedicated to the development of membranes for PEM electrolysers [28]. PEM electrolysis is sometimes referred to as "solid polymer electrolyte" (SPE) electrolysis, but the first term will be used throughout this paper.

3.1. Comparison of PEM and alkaline technology for water electrolysis

The commercial water electrolysers are based on the alkaline or the PEM technology. The electrolysis in acidic medium is no longer used, and steam electrolysis is still in the development stage. At present, PEM technology seems to have more promoters than alkaline technology [3,8,29]. Some of the proposed advantages of PEM technology are discussed hereafter, even though the comparison is not exhaustive:

i) Greater safety and reliability thanks to the absence of caustic electrolyte.

The replacement of the caustic electrolyte by pure water is certainly an advantage, but is not crucial for the safety of the electrolysers. Safety issues in water electrolysis are more related to the accidental formation of hydrogen–oxygen flammable mixtures and their possible explosion, than to the circulation of some caustic solution inside the plant. In that respect, PEM technology is very new in civil applications and has still to prove its reliability, especially with respect to the mechanical resistance of membranes [27].

ii) Some PEM membranes can sustain high differential pressures.

Although conventional alkaline electrolysers have been limited to operation at near atmospheric pressure, commercially available, advanced alkaline electrolysers already operate at 30 bar. Such pressures are not yet possible with commercial PEM electrolysers, which are limited today to 14 bar [3], even if higher pressures may be possible in the future.

iii) Possibility of operating at high current densities [28–30].

High current densities are also possible with advanced alkaline electrolysers, but they imply higher power consumption for the same hydrogen production, so they are often avoided. The operation of an advanced alkaline electrolyser up to 12000 A/m^2 is presented in this paper.

iv) High efficiencies for PEM electrolysers [8].

Crockett et al. [8] state that alkaline electrolysers cannot match the performances of PEM electrolysers. They report that efficiencies in the range 85–93% have been measured at 80–100 °C with PEM electrolysers in several studies, performed in the period from 1975 to 1990. However, such efficiencies differ from the ones encountered in actual commercial products. On the other hand, similar efficiencies have also been measured with alkaline electrolysers, as reported in this paper.

The efficiency of some commercial electrolysers of 1 Nm^3/h H$_2$ capacity is presented below. The power consumption of auxiliaries is relatively important at such low capacities. The specific power consumptions are the ones stated by the manufacturers.

At full load, the specific power consumption of a PEM electrolyser by Proton Energy Systems is approximately 6 kWh/Nm^3 H$_2$ (58% efficiency HHV), as compared to 4.6 kWh/Nm^3 H$_2$ (76% efficiency HHV) for the alkaline electrolyser by Hydrogen Systems and 5 kWh/Nm^3 H$_2$ (70% efficiency HHV) for the alkaline electrolyser by Casale Chemicals. Some conventional alkaline electrolysers, which have a very low cost, have a higher consumption. For example, the alkaline electrolyser by PIEL has a consumption of 7.4 kWh/Nm^3 H$_2$ (47% efficiency HHV). All the characteristics cited above concern the units of 1 Nm^3/h H$_2$, where the power consumption of auxiliaries is relatively important.

These figures must be handled with care, because it is not always clear to what current density they refer. However, the figures show that the efficiency of commercial PEM electrolysers is actually lower than the efficiency of advanced alkaline electrolysers. This trend may change, of course, in the future.

A clear disadvantage of the PEM electrolysers is the requirement of ultra-pure water, with a conductivity of approximately 1 μS/cm, because the membrane/electrode assembly is highly sensitive to even low levels of water impurities. Alkaline electrolysers generally require water with a conductivity of approximately 5 μS/cm, but they can also tolerate higher quantities of impurities.

Independently of the technology used, PEM or alkaline, a compromise will always be necessary between cost and performance, since a better performance generally requires a higher cost.

The conclusion of the authors from this comparison is that the actual performance of PEM and alkaline technologies is similar and both technologies will share the market in the near future. In addition, both technologies have still a great potential of cost reduction and performance enhancement.

3.2. Comparison of conventional and advanced alkaline electrolysis

During the last decade, several technological advances have been implemented in alkaline electrolysers, called 'advanced', as opposed to the 'conventional' alkaline electrolysers based on older technology. Some technological advances are summarized below:

i) Bipolar arrangement

The cell stack, generally constructed as a filter-press, became much more compact, using the bipolar arrangement, where the cathode of one cell is at the same potential as the anode of the previous cell. Instead of connecting each cell electrically, only the cathode of the first cell and the anode of the last cell are connected to the power supply.

ii) Zero gap geometry

The space between the electrodes and the diaphragms has been minimized, so that the arrangement

became more compact and the electrical resistance of the liquid electrolyte has been reduced.

iii) Activated electrodes

The old electrodes, generally based on stainless steel, have been replaced by more active ones, often based on nickel. Recently, the efficiency of the electrodes has been increased further, by the deposition of activators on the electrodes.

Some efficiencies of electrodes implemented in industrial electrolysers are cited below:

For the GHW electrolyser at the Munich airport, producing 94 Nm^3/h H$_2$, an efficiency of 78% (HHV), corresponding to a specific power consumption of 4.5 kWh/Nm^3 H$_2$, has been reported at 30 bar pressure and a current density of 7000 A/m^2 [31,32].

The 26 kW electrolyser of the PHOEBUS demonstration plant at the Research Centre Jülich (KFA), supplied by Metkon–Alyzer and equipped with activated electrodes by KFA, achieved an efficiency of 88% for an average annual power of 10 kW from a PV field and an average electrolyte temperature of 60 °C [33].

In the frame of the EUHYFIS project, co-funded by the EC, the Casale electrolyser showed a specific power consumption of 4.3 kWh/Nm^3 H$_2$ at 80 °C and a current density of 4000 A/m^2, which corresponds to an efficiency of 82% (HHV) [34].

Note that Casale has acquired all rights regarding the electrolysers by Metkon, which dismissed all activities, and continues the developments of the Metkon–Alyzer technology.

iv) Safety and reliability

The safety of modern, advanced electrolysers has been greatly enhanced by a fail-safe design, detecting and controlling any abnormal condition of the internal process, or consequent to any failure of plant components. The reliability of the advanced electrolysers has been increased by choosing components of high quality and by applying quality assurance and quality control procedures along the design and construction phase. In this way, the life-span of the electrolysers has been increased and the maintenance interventions have been minimized [35].

3.3. Design of the hydrogen generation section for the HELPS project

The choice of a commercial electrolyser for a given application is not straightforward. It must be based on performance, safety and cost considerations. As far as performance is concerned, it must fulfill the system requirements as a minimum, but may be better if safety and cost considerations remain unchanged. The design of the system has established a number of technical requirements, which are presented in detail in the following subsections.

3.3.1. Hydrogen delivery pressure to the storage section

Generally, the hydrogen delivery pressure from the electrolyser is equal to the operating pressure. A minimum pressure of 10 bar has been chosen for the delivery to the storage section, because lower pressures are not practical for conventional tanks nor metal hydride tanks. There are commercial electrolysers delivering hydrogen at 10, 13 and 15 bar pressure. However, there are also commercial electrolysers operating at 1–5 bar pressure, which can be coupled to a hydrogen compressor, delivering hydrogen at any pressure between 10 and 30 bar at similar cost. With low cost electrolysers, even with the additional cost of the compressor, the overall investment cost is half that of electrolysers delivering hydrogen under pressure. On the other hand, the electrical power consumption is twice as high in the case of the system comprising a low cost electrolyser plus a compressor.

3.3.2. Oxygen delivery pressure to the storage section

If the fuel cell operates on oxygen, the oxygen produced by the electrolyser must also be stored. Again, there are similar considerations as in the case of hydrogen. From actual offers, there are three main possibilities at comparable investment cost:

a) A low-cost conventional alkaline electrolyser with two compressors for hydrogen and oxygen, respectively. Hydrogen and oxygen can be delivered at pressures up to 30 bar.
b) A PEM electrolyser, delivering hydrogen at 13 bar, coupled to an oxygen compressor, which will compress the oxygen to 13 bar.
c) An advanced alkaline electrolyser delivering hydrogen and oxygen directly at 15 bar.

3.3.3. Hydrogen purity

The standard purity of hydrogen at the outlet of an electrolyser is circa 99.8 vol.%. This hydrogen is pure enough to be fed into a PEM fuel cell. However, hydrogen to be fed into state-of-the-art metal hydride tanks must have a much higher purity, i.e. 99.999 vol.%. So, in the case of the system under study here, a hydrogen purification unit, consisting of a deoxidiser and a dryer, is necessary.

3.3.4. Electrical power consumption

It is useful to compare the electrical power consumption of different electrolysers, because electricity consumption generally represents the main operating cost. The power consumption of an electrolyser depends mainly on the power consumption of the stack for the electrolysis itself. For a given cell area, it is possible to perform the electrolysis at low current density with high efficiency but with a great number of cells, or at high current density with low efficiency but with a smaller number of cells. Each manufacturer must make a choice, but few manufacturers have probably the time and tools to find the optimum.
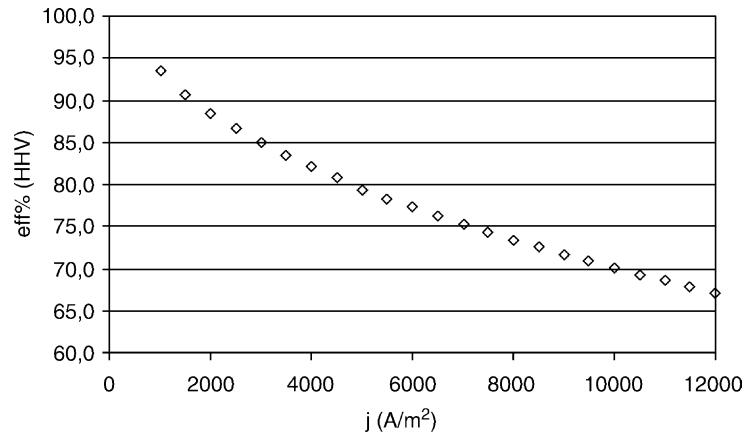
Fig. 3. The efficiency (based on the HHV of hydrogen) of the cell stack of a CASALE electrolyser at 80 °C and 3 bar, as a function of the current density.

In order to produce a certain quantity of hydrogen, the higher the current density applied, the smaller the number of cells needed for a given cell area. So, by choosing a high current density, the stack is more compact and has a lower cost. At low current density, the dc power must be supplied as low current–high voltage, while at high current density the dc power is supplied as high current–low voltage. This versatility may be used to directly connect the electrolyser to a dc power supply such as a photovoltaic field. Whether connected to a photovoltaic field or to the grid, the total power needed at high current density is higher than in the case of low current density.

In Fig. 3, the efficiency of the stack of an advanced alkaline electrolyser with activated electrodes is presented. It was calculated by dividing the HHV of hydrogen (3.509 kWh/Nm^3 H$_2$) by the specific power consumption of the stack, taking into account a Faradaic efficiency of 96%. The measurements were performed on a CASALE electrolyser at 80 °C and 3 bar pressure, equipped with recently developed proprietary electrodes.

As can be seen in Fig. 3, the efficiency of the electrolyser drops from 89% when operated at 2000 A/m^2 to 67% when operated at 12,000 A/m^2. The number of cells required to produce a given quantity of hydrogen at 2000 A/m^2 is approximately six times the number of cells required at 12000 A/m^2. This means that the price of the cell stack is approximately six times higher in the first case. The cost of the cell stack is only a contribution to the total cost of the electrolyser, but a total cost decrease of 10% is possible. On the other hand, the power consumption will increase by approximately 20%. So, a compromise between investment and operation cost must be found for each electrolyser.

The efficiency of some conventional alkaline electrolysers is lower than 65% at any operating current density. The high electrical power consumption increases the operational cost, which is always much higher for conventional electrolysers than for advanced ones.

However, for emergency back-up systems like the one studied here, which is supposed to be in operation for a few hours or a few days per year, the operating cost is not very important compared to systems operating continuously.

4. Hydrogen storage

The hydrogen storage will be composed of a conventional pressure tank and one or more metal hydride tanks. The minimum discharge pressure of both tanks has been calculated by taking into consideration the maximum operating pressure of the fuel cell (2.5 bar) and a 0.5 bar pressure differential to compensate for the pressure losses in the piping and the control valve. At the time of writing, the design of the hydrogen storage section is not complete, because it depends on several parameters of the hydrogen generation and fuel cell sections, which will be clearly defined later in the project.

The conventional tank is required to supply the fuel cell with hydrogen upon power interruption. It has been calculated that a 1 m^3 tank gives to our system enough versatility. This tank will be emptied until the pressure drops to approximately 3 bar. If the charging pressure from the hydrogen generation section is 10 bar, 6.4 Nm^3 H$_2$ will be available to supply the fuel cell for 94 min at the rate of 4.1 Nm^3/h. It has been estimated that this lapse of time is long enough to heat up the metal hydride tank from a low ambient temperature in winter, namely -10 °C, to the discharge temperature, with the help of the heat liberated from the fuel cell. If the charging pressure from the hydrogen section is 15 bar, a 0.6 m^3 tank can provide the same autonomy.

The design of metal hydride storage units is very flexible, because each alloy has different performance characteristics, such as hydrogen adsorption capacity, charge–discharge kinetics, operating range of temperature and pressure, heat of reaction and cycling capabilities. The absorbing capacity of practical commercial metal alloys varies from 1.5 to 2.5 wt.%, so the capacity of the complete storage tank lies in the range from 0.8 to 1.5 w.%. The reaction heat of most hydrides lies in the range 0.25–0.5 kWh/Nm^3

(10–20 MJ/kg) of hydrogen. Operating pressures usually vary from slightly below atmospheric pressure to 10 bar, but they can reach more than 150 bar at high temperatures (>500 °C).

Metal hydrides can be roughly divided into three categories [1]:

a) LaNi$_5$-based alloys;
b) Ti-based alloys; and
c) Mg-based alloys.

The first two categories adsorb and desorb hydrogen (1.4–3 wt.%) at low temperatures (up to approximately 80 °C), whereas magnesium alloys have higher capacities (up to 7 wt.%) but operate at much higher temperatures (230–400 °C).

In order to integrate the metal hydride tank with a PEM fuel cell, only metal alloys with low dehydriding temperatures (<80 °C) can be employed. There is still a large choice of metal alloys. The desorption temperature may be very low, for example 25 °C, with a concomitant low heat duty for discharging, but the desorption temperature would be easily attained during the summer days, increasing the pressure in the tank, with a risk of hydrogen being released through the safety valves.

More than one metal hydride tank may be installed in parallel, in order to increase the flexibility of the system and facilitate the heat recovery from the fuel cells. However, the cost of the unit increases, due to the additional cost of the piping and instrumentation.

The use of the hot water from the primary cooling circuit of the fuel cell is under study. Although it represents the most efficient way of using the heat from the fuel cell, it greatly complicates the control of the operating temperature of the fuel cell, which must be finely regulated in a very small range. Actually, it is easier to take water from the secondary cooling circuit, i.e. the water coming out of the fuel cell cooler, which can be supplied at 50 °C.

According to a manufacturer of metal hydride tanks (Labtech SA), it is possible to replace the conventional hydrogen storage tank by a specially designed metal hydride tank. By using the appropriate alloy, this particular metal hydride tank will be charged at a pressure of 10–13 bar, and it will be able to automatically release hydrogen at minimum 3 bar, for any ambient temperature between 0 and 40 °C, without preheating.

5. Conclusion

The preliminary design of a back-up power system for telecommunication applications, based on hydrogen technologies, has been presented. The prototype will supply 5 kW power for 5 h, and the commercial product can be adjusted easily to longer interruptions of the grid. It is composed of a water electrolyser, a hydrogen buffer tank, a metal hydride tank and a PEM fuel cell, with the related power electronics. The design criteria for the hydrogen generation and storage section have been discussed.

In the frame of this project, it was found that the most critical part of a hydrogen system for back-up applications is the fuel cell. The fuel cell must have a higher capacity and reliability than the electrolyser, so it represents the most expensive component of the hydrogen system. As a consequence, it is advantageous to replace a hydrogen/air fuel cell by a hydrogen/oxygen fuel cell in order to decrease the cost of the fuel cell subsystem, rather than to increase its efficiency and decrease the cost of the hydrogen production and storage section. Hydrogen systems like the one presented here are designed to operate a few hours or a few days per year, and the investment cost is much more important than the operational cost.

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