Hydrogen storage, electrolysers and fuel cells: Cost-effective power management and microgrids

By Stephen B. Harrison, Dr. Oliver Borm on Mar 16, 2021 | Translate

Renewable electricity production, mainly from solar and wind, increased considerably in the last two decades worldwide. Ele
from solar, wind, and hydro are subject to daily, weekly, and seasonal fluctuations.

The higher the penetration of renewables into the electricity grid, the more challenging it is to match supply and demand.

Pumped hydro is the classical way to overcome daily fluctuations. Nowadays, there is also an increase in large-scale battery st
projects. Nevertheless, the energy storage profile of these technologies is not appropriate to overcome extended periods of
sunless 'dark-doldrums' that persist in many locations over the course of a year.

On the other hand, green hydrogen can be a clean energy vector with seasonal storage potential and can generate electricity
demand. Due to the high volatility of solar and wind power, electrolysers are not utilised to their full extent in times of dark-doldrums. Unitised regenerative fuel cells (URFC) can operate either in fuel cell mode to produce electricity from hydrogen c
electrolysis mode to produce hydrogen from electricity. Due to this flexibility, a URFC can achieve a high utilisation, or capac
factor, which can improve project economics.

Reversible SOC-based systems: high-potential URFC candidates

A solid oxide cell (SOC) can operate both in fuel cell and electrolyser mode. There are three main types of cell: anode-suppo
(ASC); metal-supported cells (MSC); and electrolyte-supported cells (ESC). Each has distinct specifications for power density,

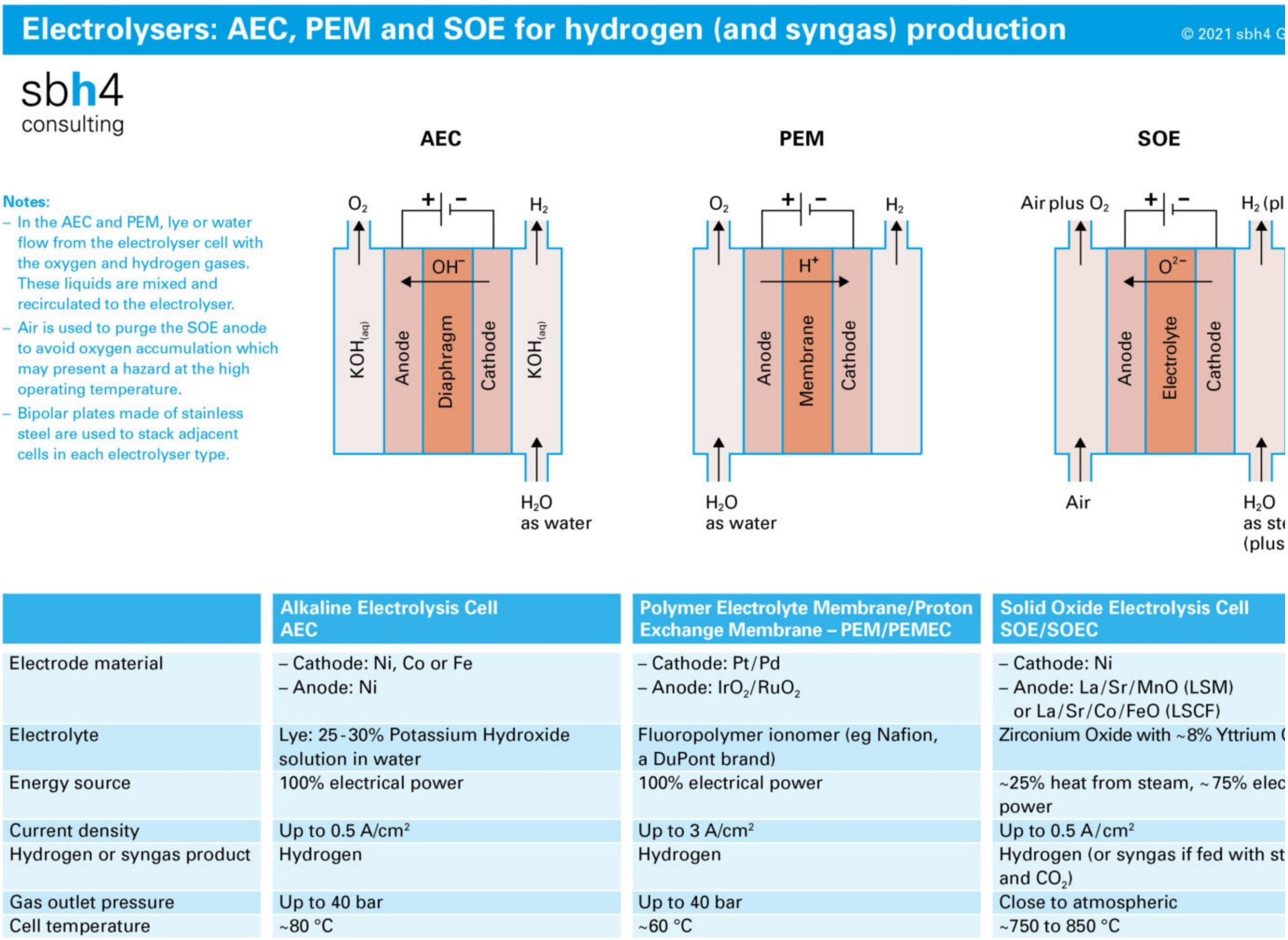
and operating temperature.

Since an oxygen ion-conducting electrolyte is utilised, fuels like natural gas, methanol, and ammonia can also be used in the f (SOFC) mode as alternatives to hydrogen.

In the early 2010s, Versa Power Systems, now a subsidiary of FuelCell Energy, conducted research into reversible solid oxide fu (RSOFCs). Their focus was on degradation mechanisms, with ultra-high current densities of ASCs in both modes with hydroge fuel. Recently, FuelCell Energy received another $3m research grant to develop RSOFCs.

Sunfire successfully demonstrated its reversible solid oxide cell (RSOC) technology within the EU-funded GrInHy project fror 2019. Its RSOC had three operating modes:

- Electrolyser: 150 kW$_{(AC)}$ input with 40Nm^3/h hydrogen output
- Fuel cell: Hydrogen fuel with 30 kW$_{(AC)}$ output
- Fuel cell: Natural gas fuel with 25 kW$_{(AC)}$ output



Electrolysers: AEC, PEM and SOE for hydrogen (and syngas) production

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Notes:
– In the AEC and PEM, lye or water flow from the electrolyser cell with the oxygen and hydrogen gases. These liquids are mixed and recirculated to the electrolyser.
– Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
– Bipolar plates made of stainless steel are used to stack adjacent cells in each electrolyser type.

	Alkaline Electrolysis Cell AEC	Polymer Electrolyte Membrane/Proton Exchange Membrane – PEM/PEMEC	Solid Oxide Electrolysis Cell SOE/SOEC
Electrode material	– Cathode: Ni, Co or Fe – Anode: Ni	– Cathode: Pt/Pd – Anode: IrO_2/RuO_2	– Cathode: Ni – Anode: La/Sr/MnO (LSM) or La/Sr/Co/FeO (LSCF)
Electrolyte	Lye: 25-30% Potassium Hydroxide solution in water	Fluoropolymer ionomer (eg Nafion, a DuPont brand)	Zirconium Oxide with ~8% Yttrium (
Energy source	100% electrical power	100% electrical power	~25% heat from steam, ~75% elec power
Current density	Up to 0.5 A/cm^2	Up to 3 A/cm^2	Up to 0.5 A/cm^2
Hydrogen or syngas product	Hydrogen	Hydrogen	Hydrogen (or syngas if fed with st and CO_2)
Gas outlet pressure	Up to 40 bar	Up to 40 bar	Close to atmospheric
Cell temperature	~80 °C	~60 °C	~750 to 850 °C

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Reversible AEM-based systems: demonstration project shows potential

The Anion Exchange Membrane (AEM) system uses a solid electrolyte. It combines the advantages of the PEM and alkaline ce utilising membranes that avoid precious metal loading.

In the last decade, Giner received several grants from the US DOE to perform research into AEM systems. Results published r show a good performance within the first 2,000 operating hours. Long-term degradation and lifetime expectation must now assessed to demonstrate this technology can be applied reliably at scale.

Regenerative fuel cells could enable Mars missions in the future.

Reversible PEM-based systems: not yet commercialised

In the 1990s, NASA conducted extended research into URFC's and energy storage to enable extra-terrestrial space activities. were based on the Polymer Electrolyte Membrane (PEM) technology.

For outer-space applications where payload is everything and stack lifetime not as relevant, URFC's based on PEM or AEM mi viable for energy storage on potential future Mars missions.

For a short period in the early 2000's, Proton Energy, now Proton OnSite – a subsidiary of NEL, offered its reversible product However, despite ongoing research projects, no commercial reversible PEM-based products are available for use at scale toda

Project parameters drive the best-fit technology

There are several challenges for integrated reversible PEM and AEM-based systems, which the RSOFC does not suffer from.

The reversible AEM or PEM system must handle humidified gas streams in the fuel cell mode, but liquid water will be in conta membrane in the electrolysis mode. Each mode must therefore consider two-phase flow optimisation. The pressure different fuel cell mode is low, at 0.3 bar but very high in electrolyser mode – up to 30 bar. This places high sealing loads on the equip

On the other hand, RSOC systems operate at atmospheric pressure. Therefore, hydrogen generally needs to be compressed electrolyser. A hydrogen compressor may require maintenance every 4,000 to 8,000 hours. Compressor operation is especiall challenging if the power is to be derived from an intermittent variable renewable energy source, because the compressor pre stable operation. This constraint makes RSOC systems unsuitable for off-grid applications.

Limitations of reversible systems

The spread in operating voltage is challenging for power electronics in URFC systems. The operating voltage in electrolyser m twice as much as in fuel cell mode meaning that the area-specific current densities are doubled. This results in 4-6 times high input (AC) of the electrolyser than power output (AC) in fuel cell mode. The implication is that the ratio of electrolyser input to fuel cell output power cannot be chosen freely – they are inextricably linked by this ratio.

PEM fuel cells, in particular for mobility applications, are optimised for a fast start up and a high power output. Their expecte lifetime is about 10,000 hours. On the other hand, an electrolyser stack would be expected to have a lifetime of at least 60,0 to be economically viable. There is a wide gulf between the requirement versus performance.

A PEM or AEM based reversible system could potentially be used for off-grid energy storage applications. The benefit would when hydrogen storage is incorporated, the system could have a higher energy storage capacity than currently available batte technologies. In this application, due to the maximum stack lifetime, multiple stack replacements would be necessary over th of 20 years (175,200 hours) of operation which is the typical lifetime expectation for an infrastructure project.

When considering the cost of frequent stack replacements, the economic benefit of an URFC compared to a similar system b separate devices (an electrolyser and a fuel cell), becomes questionable. The economics of integrating the electrolyser and a are also compromised because different balance of plant (BoP) components, for example power electronics or gas cleaning u which are necessary for each operating mode.

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Independent fuel cells and electrolysers with hydrogen storage offer flexibility

Separate fuel cell and electrolyser units can add flexibility when integrated into one system or product because each elemen optimised according to the system requirements.

This is the design concept of the recently launched LAVO system. It is targeted at consumer markets and integrated one 5 kV fuel cell and two 2.5 kW AEM electrolysers with a predicted stack lifetime of about 30,000 hours. That would result in a stack replacement after 10 years of operation, with an assumed annual utilisation of 3,000 hours.

The electrolyser produces hydrogen at a pressure of 35 bar for storage on a newly designed metal hydride system that stores kWh of electricity. That corresponds to 2.4kg of hydrogen, assuming a fuel cell efficiency of 50%.

Using a pressure vessel to store hydrogen at the electrolyser output pressure of 35 bar, compressed gas hydrogen storage cou favourable for applications where space and portability are not the priority. To achieve the same capacity at this pressure, the cylinder volume would need to be eight times more than a metal hydride storage system.

The hydrogen purity requirements for pressurised hydrogen storage are less stringent than for metal hydride storage. PowiDia chosen to incorporate compressed hydrogen storage into their integrated off-grid power system.

In 2016, a behind-the-meter microgrid energy storage system with a separate electrolyser and fuel cell was implemented at th Nickel mine close to Nunavik, Quebec (*pictured below*) in northern Canada. Electricity for the mine is provided by a wind tur power generation is subject to fluctuations in the weather conditions.

The Raglan mine scheme uses a 350 kW-rated HySTAT-60® alkaline electrolyser and a 200 kW rated HyPM® PEM fuel cell, bot the Hydrogenics range. The ratio of electrolyser and fuel cell power is 1.75:1. If a reversible system had been selected that ratic need to be closer to 4:1. Hydrogen storage is integrated into the scheme with 4 MWh of capacity using three horizontal steel storage vessels which operate at the electrolyser outlet pressure.

Rendering of a potential future Mars base enabled by regenerative fuel cells

The future of regenerative fuel cells

For many applications, separate electrolyser and fuel cell units are more likely to fit the application rather than integrating bo functions into one unit because in the single reversible unit there is a fixed ratio of the electrolyser and the fuel cell capacitie

A single reversible unit might save some capex on day one, but long-term system performance is generally much more impor initial capex. The use of a separate electrolyser and fuel cell in a scheme means the size of each component can independen optimised. Also, the fuel cell and electrolyser technologies can be chosen separately to maximise the overall system perform according to the local requirements.

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