Cellkraft

November 2005

Backup power – Fuel cells

White paper

Backup power based on fuel cells is most suitable for applications with a power demand lower than 10 kW and energy demand larger than 10 kWh. In such applications fuel cell power sources can provide long backup times at a lower cost than batteries. Fuel cells have a long lifetime, especially in standby mode. Fuel cell power sources are maintenance-free and they are insensitive to both high and low temperatures.

Anders Ocklind

Technology

Fuel cell technology is often presented as the technology of the future for a variety of consumer applications. Currently, the technology has reached maturity and cost-competitiveness for certain niche applications for professional use. Fuel cells can particularly compete against batteries and diesel generators in backup and reserve power applications. In this document, the characteristics and applications of fuel cell backup power are described briefly, and compared to those of batteries and diesel generators.

Basics

A fuel cell converts the chemical energy of the fuel (usually hydrogen) directly to electricity. Different types of fuel cells are named after the electrolyte used in them. The fuel cell that is most suitable for backup power is the polymer electrolyte fuel cell (PEFC). Polymer electrolyte and electrodes are the parts where electricity is generated. PEFC is robust and has a short start-up time. In addition to the fuel cell stack, the PEFC system includes a number of balance-of-plant components.

Fuel cells, batteries and diesel generators

Fuel cells are direct current (DC) power sources, similar to batteries. The essential difference is that fuel is stored outside of the fuel cell, as compressed hydrogen gas or as metal hydride. A fuel cell can produce power as long as there is fuel available in the fuel storage. Fuel cells are “charged” simply by filling the tanks. In this sense, fuel cells resemble diesel generators. The capacity of a fuel cell system depends on the size of the gas storage. The continuous power depends on the sizing of the fuel cell stack.

Lead-acid battery **Fuel cell** **Dieselgenerator**

Durability

Polymer fuel cells have excellent durability both in operation and in stand-by. For example, the expected life-time of Cellkraft's PEFC systems exceeds 20 000 hours of operation, two orders of magnitude longer than needed in typical backup applications. For backup applications the life-time in stand-by mode is usually the most important parameter. Compared to batteries there is no chemical degradation in the electrochemically active part of PEFC. Therefore, the stand-by lifetime of PEFC systems is practically unlimited. A combined life-time of several tens of years can be expected (99% stand-by and 1% operation).

The energy storage, in the form of compressed hydrogen, does not have any significant "self discharge". Using the maximum allowed leakage rate (6 cm3/h) 50% of "self discharge" would take 95 years for a standard hydrogen bottle. These values can be compared to those of those for lead acid batteries that, due to their inherent chemical instability, have a life-time less than ten years even in optimal conditions (ambient temperature 20° C or less). At higher temperature the degradation rate is significantly accelerated. A rule of thumb is that when ambient temperature is increased by 10° C, the life-time is halved. Diesel generators are similar to fuel cells in a sense that, with proper maintenance, they can reach over 30 years of combined lifetime including up to 5000 hours of active operation.

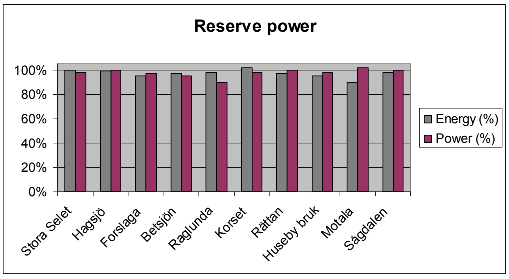
Maintenance

Fuel cell backup power sources require practically no maintenance. In principle, batteries are also maintenance free. However, some charging is important to keep up the charge level of batteries due to self-discharge. Diesel generators have the greatest maintenance needs. Maintenance includes changing the lubrication oil, filters, and start battery. Start-up tests must be done in certain intervals in order to secure availability and long life-times.

Reliability

Due to short field experience of fuel cell technology there is limited, but promising data about reliability. The technology has fundamental (properties) to reach high reliability: A fuel cell stack has simple reactions compared to batteries. In both fuel cells and batteries the cells are coupled in series. This means that the weakest cells define the performance and reliability. However, fuel cells stacks can work even if some cells are not providing full voltage. A major difference is also that that fuel in fuel cells is not stored in cell volume. Therefore unbalanced energy states can not appear. The reliability of fuel cells is dependent on many engineering choices: materials for gaskets, choice of blowers, pumps and so on. Another important factor for reliability is how well the fuel cell system is integrated, assembled and installed. In contrast, batteries have complicated chemistry but do not need complicated balance-of-plant components. The reliability of batteries is mostly defined by their age. Capacity and reliability degrade with time. Degradation is strongly dependent on temperature. Battery capacity is largely dependent on their thermal history. Diesel generators are complex systems and require a substantial amount of electrical energy for start-up. Typically the start-up is the single most critical item for the reliability of diesel generators, especially in cold conditions. With proper thermal conditioning and maintenance, diesel generators have high reliability.

Measurability



Fuel cell systems are transparent and can be monitored remotely. The stored energy can easily be measured from the pressure of the gas cylinders. The efficiency (hydrogen to electricity) is predictable. Due to this, the energy content can be expressed using units kWh or Ah. The stored energy can be measured remotely. The status of batteries is significantly more difficult to measure. The energy capacity can be measured by discharging and charging the battery, but in reality this is not often used. Usually the battery is simply replaced after a certain period of time. The uncertainties concerning capacity reduce reliability and increase costs. In order to secure high reliability, the batteries are replaced long before the problems may occur. In diesel generators the effect as well as the stored fuel can be easily measured.

Heat tolerance

The fuel cells require cooling as they operate and produce electric power. With a properly dimensioned cooling system, the fuel cell system can operate at high ambient temperatures, at least up to 50° C. The cooling of a fuel cells system is organised using a radiator, placed possibly outside of the building. In stand-by mode cooling is not needed. In stand-by mode the fuel cell system can tolerate very high ambient temperatures. No degradation is expected, even with an ambient temperature up to 75° C. This all means that the requirement for cooling can be lowered in many applications, since it is often batteries, not electronics that require cooling. In some cases, the need for energy and a service-intensive air conditioning system is removed. Diesel generators work well at high ambient temperatures if the cooling system is properly dimensioned.

Cold tolerance

Properly designed and operated fuel cell systems can tolerate very cold temperatures. Fuel cell systems can also start at low temperatures; for example Cellkraft's system can start from -33° C. There is no reduction in energy capacity or power outtake in subzero conditions. The capacity and available effect of batteries is significantly reduced at cold temperatures. Diesel generators should be continuously heated by electrical heating to be ready for start-up in cold conditions.

Backup power products

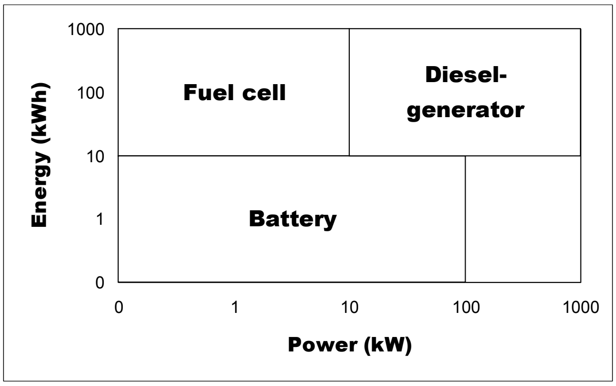
There are several producers for fuel cell backup power products. These are listed in following table.

	Cellkraft (Sweden)	P21 (Germany)	ReliOn (USA)	Plug Power (USA)	Idatech (USA)
					
Model	S-Series	Premion T	T-1000	GenCore	ElectraGen
Effect	50 W / 500 W / 1 kW* / 2 kW	3 kW	1 kW	5 kW	5 kW
Dim (wxdxh)	470x513x280 mm	667x483x470 mm	325x482x595 mm	1120x660x610 mm	600x600x1200 mm
Weight	28 kg	93 kg	54 kg	227 kg	226 kg
Voltage	-45 VDC to -55 VDC (adj.)	- 44 VDC to - 57 VDC (limit)	24 alt 48 VDC	-46 VDC to -60 VDC (adj.)	-46 VDC to -54 VDC (limit)
Ambient temp.	- 33 to + 46 °C	-5 °C to 45 °C	0 °C to 46 °C	-40 °C to 46 °C (elect. heating)	-40 °C to 50 °C (goal)
Placing	Indoor**	Indoor **	Indoor**	Outdoor	Outdoor
Noise level	<60 dBA @ 1 m	<55 dBA @ 1 m	53 dBA @ 1 m	60 dBA @ 1 m	<60 dBA @ 1 m

* Data for 1 kW system
** Outdoor cabinet option.

Applications

Small power – Large energy demand



Fuel cell power sources are best suited for the applications in which the power need is low (<10 kW) and the energy needs are high (>10 kWh). The reason for this is that the fuel cell, the size of which defines the power, is expensive while the energy storage is relatively inexpensive compared to batteries. In other words fuel cell power sources can compete in applications where required backup times are long and the effects are low. When backup times are short, batteries are usually the best solution. When both large effect and energy storage are required, diesel generators are the most competitive alternative.

Effect and energy requirements in telecom applications.

Typical effect and energy required in telecom stations are given in the table below.

Application	Power max/cont. (kW)	Energy (kWh)
Radio base station in metropolitan area	7,5 / 4,5	20
Radio base station in rural area	4,5 / 3,0	40
Radio base station in remote area	1 / 0,65	40
Telecommunication station (fixed network) in rural area	0,65	20
Radio base station critical network (TETRA) with 5 days of backup time	1,5 / 1,0	120
Radio link (seasonal backup 5 months)	0,050	200

Pioneer installation – seasonal backup for radio link

During winter 2004, a 50 W-fuel cell unit was tested on the top of a fell in Jämtland, Sweden. The energy storage consisted of 4 standard bottles of industry quality hydrogen (totalling 40 kWh electricity), stored outside. The unit was remote controlled and was in operation 24 hours a day during the testing period.

During winter 2004, a 50 W-fuel cell unit was tested in an industrial area close to Stockholm. The unit was placed in a non-heated outdoor cabinet. The temperature during the test period dropped to -20 °C. The energy storage consisted of 12 standard bottles of industry quality hydrogen, so called Europall (totalling 120 kWh electricity).

This type of small system is suitable for seasonal backup for PV-panels/batteries or for primary grid-independent power source for applications with low effects such as radio links.

Pioneer installation – Fixed network telecom station

In October 2005, a 1 kW fuel cell (model S-1000) was installed in one of the telecom stations of Swedish operator Telia. The fuel cell will automatically start in case of grid power failure and will power the telecom station. With normal power consumption (about 700W) of the station, the fuel stored (140 kWh) is enough to power the station independent of the grid for 8 days. The energy capacity (gas pressure) as well as other parameters are remote-monitored via modem.

Fuel cell

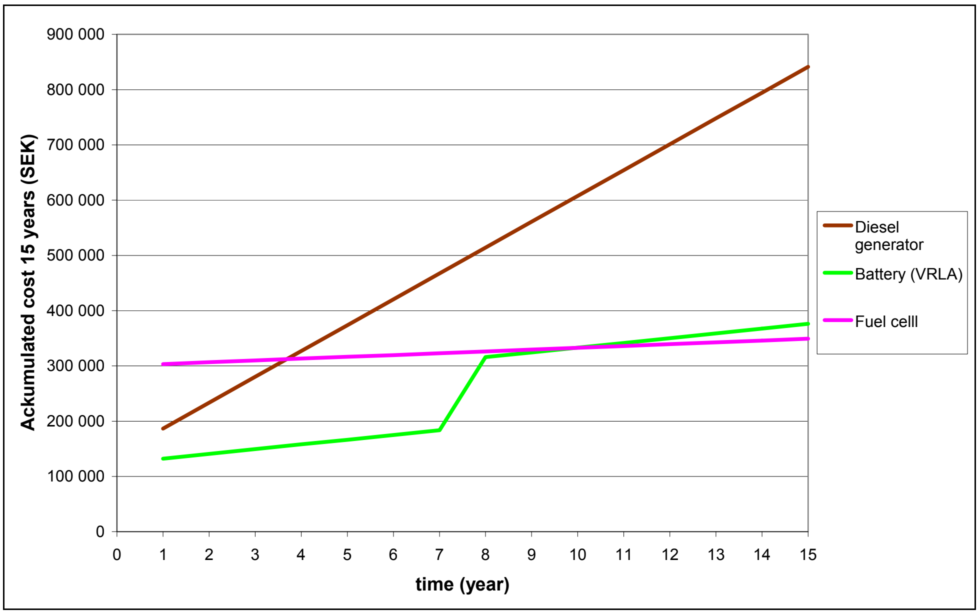
Telecommunication station and gas storage

Radio base station outside of urban area – an economical analysis

A typical European radio base station outside an urban area has power needs specified in the following table. The required back up time is 12 hours, which equals 40 kWh of stored electricity. In the analysis it is assumed that air conditioning is included in the battery alternative to keep the temperature at the right level inside the station. The analysis shows that fuel cells and batteries have similar costs when 15 years is assumed as the calculation basis for this application.

Application	Power max/cont. (kW)	Energy (kWh)
Radio base station in rural area	4,5 / 3,0	40

	FC	Battery	Diesel
Description	Fuel cell and gas storage	Lead-acid batteries and charger.	Dieselgenerator installed in shelter.
Capital cost (SEK)	280 000	110 000	120 000
Installation (SEK)	20 000	0	20 000
Lifetime (year)	15	7	30
Maintenance	Visual inspection	Visual inspection	Oil change, Test starts.
Maintenance (SEK/year)	1 500	1 500	36 000
Comments		Requires AC cooling	Requires heating
Cccling - AC (SEK/year)	0	5 913	0
Heating - Engine heater (SEK/year)	0	0	8 760
Total operation costs 15 years (SEK)	49 380	129 195	701 400
Total costs 15 years (SEK)	349 380	376 195	841 400

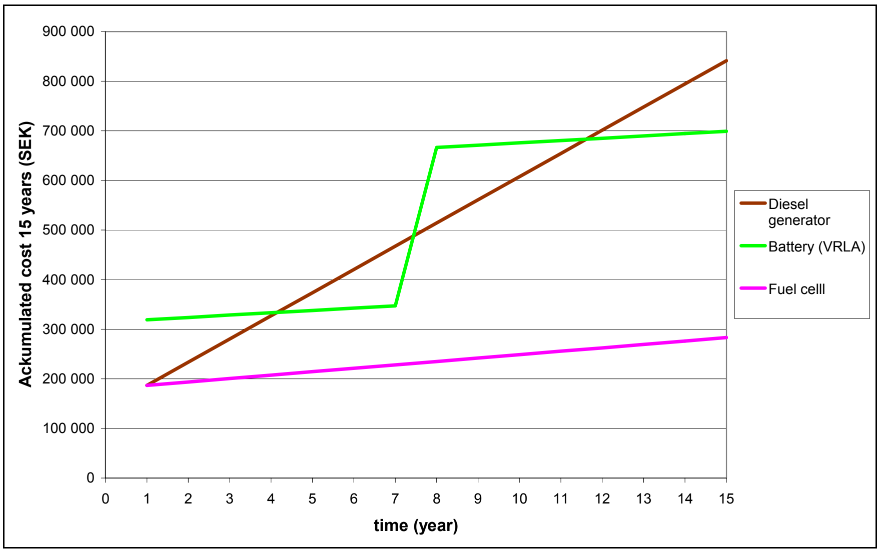


Radio base with a long backup time– an economical analysis

Critical applications have extended backup time requirements. One example of such a critical application is the TETRA-systems that are built up in Sweden, Norway, England, Netherlands etc. The systems will be used for mobile telephone communication by police, emergency service, fire-fighters, the military etc. In this type of application, fuel cells become more competitive than batteries. With fuel cells, the backup times can be extended to new levels at significantly lower cost than with any other alternative.

Application	Power max/cont. (kW)	Energy (kWh)
Radio base station in critical application with 5 days backup time	1,5 / 1,0	120

	FC	Battery	Diesel
Description	Fuel cell and gas storage	Lead-acid batteries and charger.	Dieselgenerator installed in shelter.
Capital cost (SEK)	160 000	310 000	120 000
Installation (SEK)	20 000	0	20 000
Lifetime (year)	15	7	30
Maintenance	Visual inspection	Visual inspection	Oil change, Test starts.
Maintenance (SEK/year)	1 500	1 500	36 000
Comments		Requires AC cooling	Requires heating
Cccling - AC (SEK/year)	0	1 971	0
Heating - Engine heater (SEK/year)	0	0	8 760
Total operation costs 15 years (SEK)	103 140	70 065	701 400
Total costs 15 years (SEK)	283 140	699 065	841 400



Conclusions

Fuel cells are most competitive in applications in which extended backup times are required. As the cost per energy unit is low, fuel cells open up new possibilities to extend backup times in low-power applications.

For applications in which the required backup times are shorter, the competition against batteries is harder. In these applications the fuel cells can compete if air conditioning is required for the batteries.

The stability and long stand-by life-time of fuel cell power sources are properties that make them suitable for applications in which the time periods are long. Well designed fuel cell power sources also have a long life-time in operation (>20 000h).

Maintenance free fuel cell power sources are already sold on the market. Fuel cell power sources tolerate heat better than batteries and therefore require reduced amounts of air conditioning. The stored energy and effect can also be measured remotely, another significant benefit compared to batteries.

Backup power – Fuel cells
November 2005, version eng-1.0