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Final Report

UPSeco

– a unique "plug & play" power solution for critical energy applications –

Confidentiality	Distribution List
Restricted to	Project partners, EUDP

Indhold

Objectives

The report outlines the overall project results and learning of the UPSeco project.

The report covers the following areas

- Commercial aspects
- Technical results
- Learnings and results from the deployment phase.

Commercial aspects

Opportunities

The traditional elements of a strong business case are:

- Value proposition
  - Does the solution solve important problems for the end users?
  - Is the solution unique – and it offers sustainable competitiveness?
  - Does the solution offer a paradigm shift – or is it just an improvement compared compared to competition?
- Market size
  - Does it concern a local matter – or can we expect to broaden the scope internationally?

This project addresses the solution for an important problem: Grid outages.

The vulnerability of End users to power outages is high for an increasing number of end users. The electricity grid uptime is inadequate for such consumers.

The gap between demand and grid performance is covered by Un-Interruptible Power Supply (UPS) solutions.

However, the UPS is not a new invention and it has existed since the early 1980'ties.

So, to see the motivation of this project one would have to look into the trends out there on the market:

- The cost of downtime is increasing
- Grid performance is decreasing.

This means, that the demand for the so-called extended runtime of UPS solutions is growing rapidly:; The duration of which the UPS can sustain power to the application when there is no Grid power is growing from a few minutes (short outages) towards several hours.

Today, the runtime may be provided in several ways – typically:

1. Battery storage that offers enough energy to the UPS to cover a certain Grid outage duration

2. Diesel generators that starts such that they can take over the power supply when the Grid fails.

(2) also requires a UPS – but the battery size for (2) may be relatively small as it only has to cover the consumption while waiting for the generator to start. Practically, the battery is dimensioned to also cope with

- Dealing with problems (e.g. "diesel generator does not start")
- Call/Transport time for authorized service personnel.

However, the use of diesel generators becomes increasingly problematic due to rules and regulations. Key issues are acoustic noise and emissions.

Moreover, a diesel generator installation requires

- On-site people for handling/operating the installation
- Frequent test runs (that each time also imposes a certain risk of downtime)
- Frequent service and maintenance overhauls
- Re-fuelling, fuel replacement and fuel tank cleaning.

This increasingly directs the attention towards alternative solutions.

Extended runtime battery solutions seem relevant, but they also tend to exhibit various inconveniences:

- However scalable, the cost is proportional to the required runtime
- The battery lifetime is limited
- The battery reliability is questionable and difficult to predict
- One must deal with practical issues like weight, space, fire hazards, frequent testing, thermal environment, decaying runtime capacity during lifetime, etc.

This project targets extended runtime solutions, but it seeks to

- Substantially reduce the battery size
- Replace the diesel generator by means of a clean technology: Fuel Cells.

Uniqueness

The use of fuel cells for power generation in UPS solutions is not unique and it has been pursued by a rather large number of fuel cell players.

Even very large fuel cell suppliers have by themselves pursued the UPS application unsuccessfully. One reason for this is some confusion about the actual function of the fuel cell in such "no break" systems:

- The fuel cell functions as a battery extension – it only covers the "power generator" functionality – this means that
  - It does not replace the UPS subsystem – and the UPS subsystem constitutes a major part of a complete solution

    - The fuel cell pricing must be able to compete with
        - Diesel generator solutions
        - Extended runtime battery solution
- Critical applications demand high end products
    - The development of UPS products is a highly specialised discipline.

Therefore, this project has paired the fuel cell technology with a UPS solution that offers unique benefits especially in the field of extended runtime solutions where the use of Fuel Cell technology is relevant.

Market trends

Several studies indicate that the quest for Uptime must be dealt with locally (e.g. by Gridlab, Germany).

Grid performance is increasingly challenged everywhere by a combination of

- Emerging peak power demand from EV fast charging
- The general transition from a variety of energy types into electricity and non-fossil sources
- The introduction of distributed power generation (wind power, PV etc.)
- In some regions: The reduction of the power capacity of traditional, centralised power plants, including dismissing nuclear power plants.

Thus, this project targets a global growth market.

However, after 2010 most large UPS suppliers have had difficulties in terms of earnings within their UPS activities – so the market has been characterized by

- Consolidation – large corporations acquire their smaller competitors
- They bypass their reseller network (their former partners) and sell direct to the end users
- Reduction in innovation and R&D – typically re-focusing into
    - Product maintenance
    - Cost reductions
- Increased focus on software-based services – like
    - Digitization
    - Service and maintenance
    - Even "power-as-a-service" approaches
- Re-design of the supply chain (outsourcing to the Far East, mainly).

A key challenge has been the lack of product differentiation – many suppliers have invested vast amounts of money in rather narrow performance improvements just to discover that "the end user cannot see the difference".

So, the end users' choice becomes increasingly based on price or brand.

One technical reason for this is – for decades – a rather narrow R&D focus on improving power efficiency – a priority that has been challenged by facts like

- The evolution is to some extend driven by semiconductor evolution – so it is likely to become similar for all the players in the arena, just a matter of time…
- The efficiency performance is already rather high (94-95% and up) – so they all tend to stumble up just below the theoretical 100% limit – the result is decaying product differentiation
- Substantial marketing efforts have been directed into blindfolded "power efficiency messages" despite the fact that energy savings in other areas would be substantially more important to the customer (e.g. power consumption for cooling of IT equipment is typically 10-20 times higher than the power loss in an UPS).

After this technological adventure many of the large UPS suppliers have reduced their R&D spending and started looking into the software arena.

Commercial targets

The project targets power generation for extended runtime in uninterruptible power supply units (UPS). The solution is based on high temperature fuel cell power generator in combination with state-of-the-art UPS system based on LivingPower™ (power virtualisation). Typical specifications are

- Load range 5-40 kW, uninterruptible output power (no-break), 3-phase AC output
- Extended runtime applications from 30 minutes to several hours (like 4-12 hours).

At the start of this project, this was complementary to most other fuel cell applications targeting telecom base station applications (<5 kW, 48V DC (battery-fuse functionality), a simple replacement of extended runtime battery).

Examples of typical end user segments in this power range AND asking for extended runtime would be

- Mission Critical Applications requiring Extended Runtime – like
  - Small-Medium enterprises (IT, network, internet access, local servers and data, security)
  - Hospitals (most countries except for Denmark uses small decentralised installations)
  - Traffic control systems (bridges, tunnels, airports, traffic lights)
  - Small data centres (like software house running their own customers at an in-house server farm)
  - Energy distribution (transformer stations, grid switching stations, grid surveillance and management)
  - Fibre network hubs
  - Some military installations.
- Safety solutions (normally always with extended runtime)
  - Emergency light
  - Handling of lifts

- Smoke ventilation
- (Fire) doors and gates
- Water pumps (sprinklers, evacuation of water).

Except for emergency light, most Safety solutions can tolerate minor outages (i.e. they do not require no-break).
LeanEco's LivingPower™ solution can deal with both these targets simultaneously with strong and unique benefits.

Market size

The overall UPS market is in the order of USD 14 B (2014, Frost & Sullivan). However, this market is segregated into a variety of segments like

Size	Topology	Type	Typical applications	Extended runtime
1-phase 0-1 kW	Off-line UPS	"Shoe-box UPS"	Home, SOHO	Rarely
1-phase 1-3 kW	Off-line	Rack mount	Home, SOHO	Rarely
1-phase 1-3 kW	On-line	rack mount	IT all-in-one rack	Extra battery pack (rarely)
3- phase 3-15 kW	On-line	Stand-alone	Enterprise (IT)	Some
3-phase 10-100 kW	On-line	Modular, scalable	Enterprises (IT & mfg) Small data centres Hospitals Fibre networks Some military installs	Often Yes Yes Yes Yes
3-phase 25-200 kW	On-line	Modular, scalable	Enterprises (IT & mfg) Small-medium data centres	Often Yes
3-phase 200+ kW	On-line	Modular, scalable	Data centres	Yes
3-phase 15-1000 kW	On-line	Stand-alone	Data centres	Yes

The demand for extended runtime is limited to a certain percentage of professional/commercial applications (the so-called attach rate).

70% of the UPS market relates to 3-phase products.

As a rule of thumb (but not always true), the professional applications always apply so-called on-line topology that both bridges power outages (no-break) AND protects against grid disturbances. The latter is important, since the end user equipment is often very expensive and vulnerable, and it must be shielded against potentially destructive grid disturbances.

The modular UPS appeared in 2004, offering

- "Pay-as-you-grow" scalability by adding/removing UPS modules
- Built-in redundancy
- Reduced time-to-service

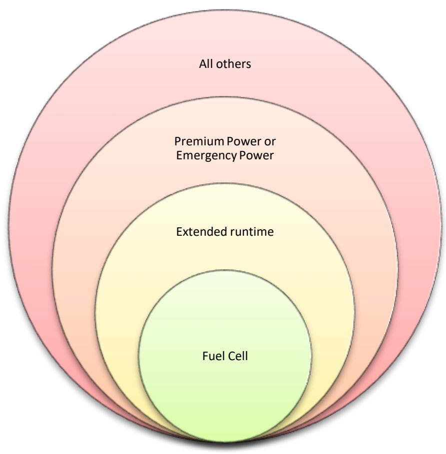
- Supporting the so-called “configure-to-order” sales approach.

The modular UPS market of Europe is in the order of Euro 260 mio, growing annually by 15% (Frost&Sullivan).

The “green” box of the table marks the targeted UPS segments of this project.

Addressable market for fuel cell based UPS extended runtime solutions

The market for the fuel cell generator equipment for UPS extended runtime power generation is limited by the so-called “attach rate” – i.e. the percentage of end users that actually applies a fuel cell solution:



This attach rate of “extended runtime” might be as low as 5 to 20%. It varies strongly on the geography (i.e. local grid performance) and the end user segment (application).

On top of this, this extended runtime market must be shared with batteries and diesel generators.

Presumably, the market of high-power solutions (say 200 kW to several MW) is generally not likely to apply

- Batteries due to the impractical size (buildings!) and cost of extended runtime installations
- Fuel cells due to their prospected price per kW (this may change, however).

In Denmark, the market for UPS (and even more for extended runtime) is limited but growing. The local awareness and visibility of this business is rather low in Denmark. However, most other countries will in general show much higher penetration of UPS solutions as well as extended runtime solutions. Trips to German customers since 2015 confirm this.

In other words, this adventure is born to be global and it will be difficult to base it solely on the Danish market. However, some segments in Denmark have shown understanding and interest – like

- Fibre network operators
- Small datacentres (however, there have been very few start-ups after 2010).

Macro trends and market drivers

The power protection market is subject to a variety of impacts that evolves over time of which some are mentioned here in the form of "postulates":

- The vulnerability to power outages increases due to
    - Demand for mobility and connectivity
    - Automation
    - Internet-of-Things
    - Remote applications and services
    - Streaming services
    - etc.
- The power quality of the Grid declines
    - Deregulation of the energy market (less capacity margin, "if-you-want-uptime-you-must-pay-for-it"…)
    - Increased penetration of energy sources that are less predictable (wind power, solar, decentralised)
    - Power capacity constraints (especially in growth areas)
    - Phase-out of nuclear power plants
    - Climate changes (lightning, hurricanes, flooding…)
- Cloud computing/remote services
    - Enterprises will place their applications and data bases remotely at service providers (datacentres) – however remotely oriented, they become increasingly dependent on
        - Remote access to data and services
        - Communication/mail
        - Local networks and work places
        - Local work data and servers
        - Local security systems
    - Growth: All enterprises will need to have a small-medium installation for this
        - High-end/High-availability
        - Often with extended runtime
        - Typically, 5-40 kW power capacity
    - Datacentres will grow even bigger and pursue "lowest cost per square meter" – size matters…
    - Consequently, the mid-size systems will more or less disappear (like UPS from 100-500 kW) – the applications will move to service providers
- Manufacturing enterprises
    - On-time delivery and quality becomes increasingly important
    - A major part of outsourcing is shifted back into the proximity of the customers as cost goes up in Far East and as on-time delivery becomes increasingly important
    - Customers will require their suppliers to ensure "business continuity" like protecting their business against loss of power

- Legal trends
    - Reviews, auditing and certification of infrastructure and IT will become part of the annual review of enterprises due to the dependency of businesses of their data, security and business continuity
- Networks
    - Cable TV networks will transit into fibre networks
    - The applications will expand from “TV-only” to also comprise commercial business applications
    - This raises the demand for high-end solutions including robustness against power loss
- Traffic control trends in automotive
    - Advanced traffic control systems keep becoming more and more integrated with the individual vehicle navigation and even control and operation – like for autonomous cars and trucks
    - This results in a large growth in traffic control systems and services – as well as associated means to ensure uptime and availability of such systems and services.

Overall, there is a strong trend pointing of increased awareness and use of protection against power loss. This includes all countries and regions and is no more limited to areas with a poorly developed infrastructure.

The technology landscape

The LivingPower™ concept

Based on power virtualisation (a LeanEco invention), the UPS system has the advantage of being able to blend grid power, battery power, generator power with back-up function or no-break function on any outlet.

This means, that an end user can install the system as a normal UPS and then reconfigure at any time – even during operation – by means of a configurator, but with no changes to panels or cabling.

Example:

A system is initially installed as a traditional UPS

- No-break power for servers with 10 minutes of battery runtime
- Cooling is feed by the grid (no backup, not no-break).

If the end user at a later stage wants to extend the runtime, he would need also to include the cooling into the UPS/backup system (otherwise the system shuts down after 5-10 minutes of operation due to overheating).

In the case of a traditional UPS solution, this would be a “project”:

- Add more batteries to the server UPS (UPS #1) or connect fuel cell power generator modules to it
- Install a UPS #2 for the server cooling (same as UPS #1)
- Install more batteries to UPS #2 or add fuel cell power generator modules to it (to get the same runtime as for UPS #1)

- Install panels and cabling for the new UPS#2 (and for the cooling).

Using the LivingPower™ solution makes this radically more elegant:

- Add more batteries or connect fuel cell power generator modules (to cope with server and cooling consumption during the extended runtime)
- Re-configure the system via the user interface so that the system now includes the cooling as a load to be provided for during grid outage (the socalled VirtualGenerator™ function) and press ENTER
- (There is no need to buy more UPS capacity nor to install more cables).

In this way it becomes very simple to – at any time – perform even major changes to the runtime system runtime performance. This favours all DC power sources like batteries or fuel cells.

The marketing wording is “keystrokes instead of projects…”.

The key benefits are:

- Extended runtime based on DC (batteries/fuel cells) becomes cost competitive to diesel generators
- Simplicity – easy and low risk to introduce at a later stage.

Implementing extended runtime

There are several alternatives when implementing extended runtime in UPS systems:

- Batteries (Lead Acid batteries or Li-ion batteries)
- Fuel cell power generator
- Diesel generator.

This section outlines various aspects of choosing among the different technologies.

Note: NiCd batteries are commercially available and offer a lifetime beyond 10 years. But due to the automotive trend of using Li-ion technology we have chosen to focus on this as an alternative to lead acid batteries.

Requirements to the Availability of subsystems

People invest in UPS systems in order to avoid load drops and to protect their equipment from disturbances on the Grid.

Therefore, availability is a key system parameter.

UPS availability

The UPS subsystem carries the power all the time and as such it must offer state-of-the-art availability. This is often provided by built-in fault tolerance, i.e. the subsystem can sustain output power even after a single or several faults.

Two key elements impact the availability:

- Built-in redundancy (able to tolerate faults)
- Time-to-repair.

Modular UPS systems are in most cases repairable on-the-fly, this especially applies for modular solutions.

Fuel cell availability

The extended runtime solution only becomes relevant occasionally, since most grid outages exhibit limited duration. This means that the availability requirement on this subsystem is substantially less than for the UPS subsystem.

It also means that it is possible to service and perform maintenance tasks on the fuel cell subsystem during operation – with no impact on site operation.

However, this situation changes radically in case the UPS energy storage is dimensioned for a very short on-time (like 30s) and the generator correspondingly has below 10 seconds to start. In this case, the availability requirement to the generator increases dramatically. This solution is often seen with Low Temperature Fuel Cells, where a very fast start-up allows for replacing batteries with super capacitors. The advantage is “no batteries”.

Battery availability

Battery technologies all suffer from an important element of unpredictability. Therefore, it is challenging to obtain a high availability despite frequent and recent testing.

The best measure to achieve this is to employ several battery strings in parallel thereby obtaining built-in fault tolerance.

Lifetime, service and maintenance

Lead acid batteries

Batteries today has a lifetime in the order of 10 years (lead acid). This is especially easy to achieve in extended runtime applications, where the load on the batteries is low (there are many batteries to share the load). Technically speaking, they see a low “C-value”.

Batteries are normally tested automatically by the UPS subsystem on a regular basis (like monthly). In case of problems, a service contractor is called.

For scalability, there are often parallel battery strings in extended runtime systems. This elevates the system availability.

In UPS applications, lead acid batteries are expected to last from 100 cycles of charge/discharge (deep discharge). Worst performance appears when the system battery runtime capacity is low (say 5 minutes – the batteries are fully discharged in 5 minutes).

Lead acid batteries are not suitable for high temperature applications (they should stay in the range 10-20 degrees C). Operation at temperatures above 30 degrees may severely degrade the lifetime.

Li-Ion batteries

In UPS applications, the expected lifetime is better than the lifetime of lead acid batteries.

The real advantages versus lead acid batteries become apparent in applications that demand many charge-discharge cycles – like SmartGrid or solar applications with daily cycling. Such applications are not suitable for lead acid batteries.

However, the charge-discharge cycling load of traditional UPS applications is normally given by the self-test scheme, i.e. in the order of 10-20 annual cycles.

Diesel generators

The maintenance of a high availability diesel generator is rather resource demanding. For professional applications like UPS, it is normal to have a weekly test run of the generator for a several hours.

Diesel generators exhibits two typical fault behaviours:

- They cannot start (large amount of reasons)
- The do start, but they stop running when reaching a certain operating temperature (e.g. after 1-5 hours).

It is normally required to have in-house people with the right expertise to handle tests and issues.

On an annual basis, there is a service and maintenance visit by the supplier, and some years a major overhaul replacing fuel and cleaning the fuel system.

With the right care a diesel generator installation can serve for 15-30 years.

Fuel Cells

To be a strong solution fuel cells must have a lifetime beyond 10 years.

A selling point would be that fuel cells are expected to be much easier to maintain than diesel generator installations – like

- No in-house expertise should be required
- They support automatic testing (like for batteries)
- Very few moving parts
- No problems with diesel fuel ageing
- Low cost service contract is possible delegating all maintenance and service to the service contractor (annual service contract level at say 5% of the generator price).

Price levels

Below is given two simple comparisons of initial cost (the cost of installation, racks, floor space, cabling etc is not included).

Basic assumptions of the example are (by year 2015)

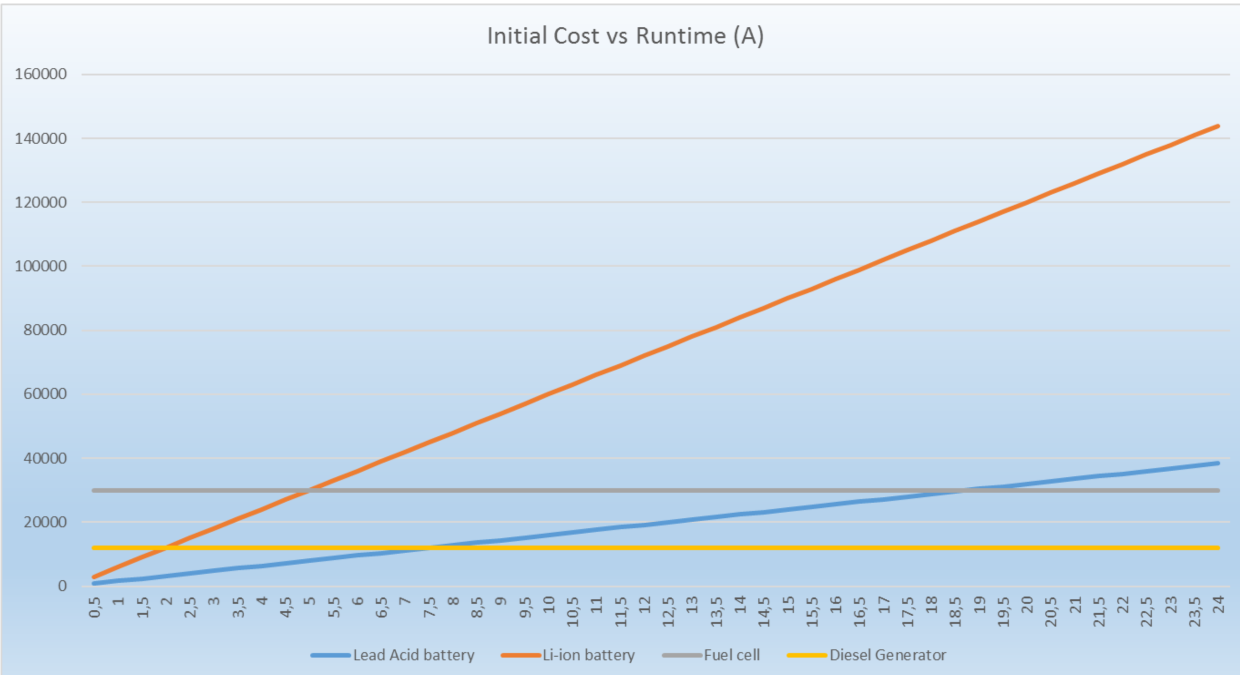
- Power demand: 10 kW
- Lead acid battery cost: 160 Euro/kWh – is kept constant (sales prices may be substantially higher)
- Li-ion battery cost: 600 Euro/kWh – the price is assumed to drop over time due to electric automotive market growth – even to a level below the price of lead acid batteries
- Fuel cell cost: 3.000 Euro/kW (A) – it is assumed to drop over time to say 1.000 Euro/kW
- Diesel generator: 1200 Euro/kW (professional generators are relative expensive at low power levels – the cost/kW drops down to say 3-400 Euro/kW at higher power levels).

Form a cost point-of-view, the modular approach of fuel cells does exhibit the advantage of a more or less fixed cost per kW. For diesel generators, the cost per kW rises to rather high levels when the power capacity goes down. This will open a window for fuel cells at low power levels, but also make it rather difficult to play a role in large power capacities, where diesel generators tend to reach 3-400 Euro/kW.

Fuel cost does not play any significant role in the comparison due to the limited runtime over life.

Initial Cost comparison – 10 kW system – early scenario (A)

Lead Acid battery	Li-ion battery	Fuel cell	Diesel Generator
Price/kWh [Euro]	*Price/kWh [Euro]*	*Price/kW [Euro]*	*Price/kW [Euro]*
160	600	3000	1200



Remarks:

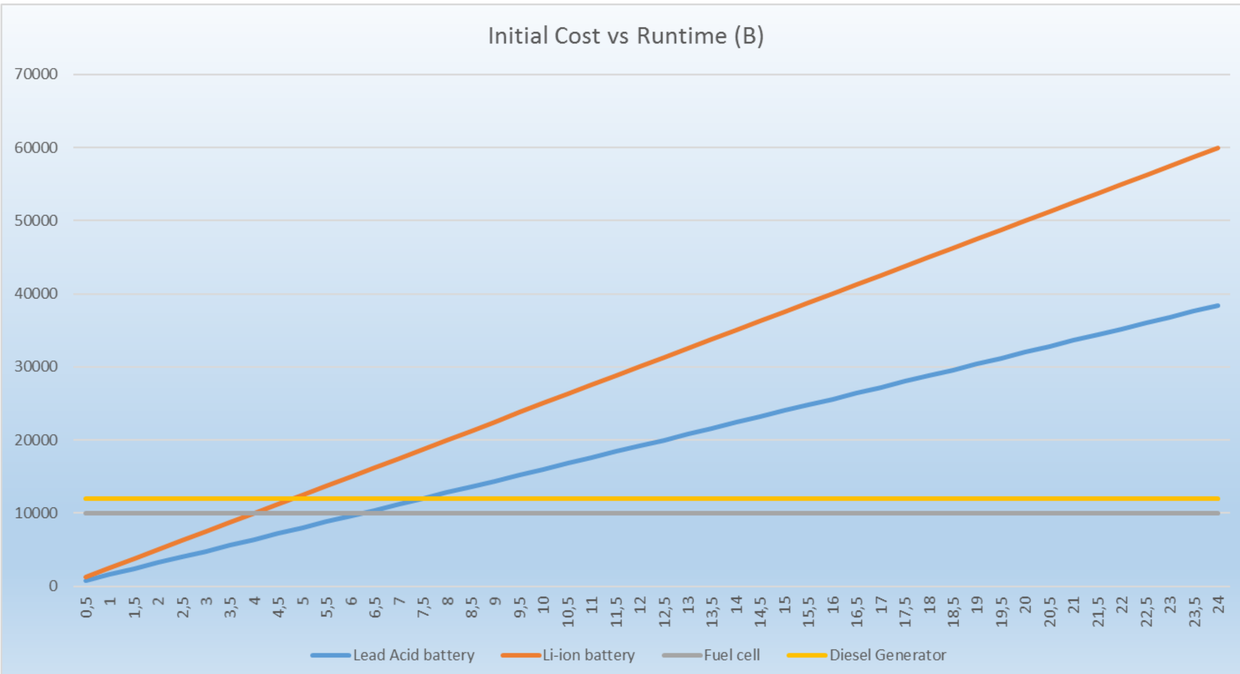
- Lead acid batteries beat all up to 7 hrs of runtime, where Diesel Generator takes over
- Fuel cells become comparable to lead acid batteries at 18 hrs of runtime and higher
- Li-ion batteries are more cost-effective than fuel cells up to 5 hrs of runtime.

So – basically – the cost of fuel cells is far too high in this phase to be able to compete with the alternatives for UPS extended runtime applications.

Including the installation cost of a diesel generator would elevate this price to 20 kEuro, but it would not change the conclusions with respect to the fuel cell technology.

Initial Cost comparison – 10 kW system – future scenario (B)

Lead Acid battery	Li-ion battery	Fuel cell	Diesel Generator
Price/kWh [Euro]	*Price/kWh [Euro]*	*Price/kW [Euro]*	*Price/kW [Euro]*
160	250	1000	1200



Remarks:

- Lead acid batteries are best up to 6 hrs of runtime, where Fuel Cells take over
- Li-ion batteries are more cost-effective than fuel cells up to 4 hrs of runtime.

So – basically – the cost of fuel cell takes over the role of the diesel generator in UPS extended runtime applications.

Including the installation cost of a diesel generator would elevate this price to 20 kEuro, and this would further underline the advantage of fuel cells.

To become a winning technology, the installation of fuel cells must be safe, uncomplicated and low priced.

Aspects of space and placing

These are not key driving parameters, but in some cases such circumstances can make one technology more feasible than others.

Batteries

Large lead acid battery installations take up a lot of floor space and they may impose serious weight issues.

Li-ion batteries are more energy dense and their weight is substantially lower than lead acid batteries.

General, batteries are considered to be a fire hazard, and according to some standards they are not allowed to be placed in the same room as the application equipment (e.g. IBMS standard for server rooms).

Li-Ion batteries exhibit certain worries in case of fire and they need special care in terms of installation and safety.

Diesel generators

The noise, weight and vibrations of diesel generators often makes it problematic and costly to place and install them – even for low power installations.

The fuel tank should be outdoor, easy to access by a fuel supplier, and to minimize fire hazards. Placing the fuel at the rooftop is no more considered a feasible solution.

Fuel Cells

The weight and space of fuel cells is proportional to the power level, and the fuel has a high energy density that is comparable to diesel oil (if the higher efficiency is included). This makes it a good case for many hours of runtime.

As for diesel generators, the fuel tank should be placed outdoor in most cases.

Hydrogen fuel is very elegant when the storage is small (i.e. low power, limited hours of runtime). However, this technology is not considered scalable to say beyond 30 kW / 4 hours runtime (equivalent to 12 cylinders @ 200 bar), since space and approvals tend to become comprehensive.

CSR and environmental restrictions

Some end users cannot get a permit for installing a diesel generator. In some regions this is due to noise restrictions, whereas in other regions it is due to emissions. In most large cities in Europe this is a problem today.

Therefore, fuel cells and batteries have a strong selling point in terms of low noise and low emissions.

Unfortunately, the formal regulations behind such issues are local and difficult to determine.

Some end users may favour a Cleantech solution for that reason. However, the fuel must then exhibit a zero-carbon footprint.

Anyway, PV solutions are often preferred since they make a clear and visible statement on the general CO_2 footprint of the company.

Commercialisation

Barriers of market entry

The fuel cell technology

According to the simple price analysis, price will be a blocking point for commercialisation in the target segments of this projects in the early years.

The threshold is likely to be when fuel cell price per kW decreases to the price level of diesel generators. This barrier will be passed first for small generators as the price per kW is high for such diesel generators.

Besides, the high temperature fuel cell technology employed in this project suffers from a rather detrimental start-up time. The consequence of this is, that the fuel cell cost must be accompanied by a rather large battery installation, too. This battery installation shall run the loads while waiting for the fuel cell to become ready.

The fuel cell start-up time is approximately 60 minutes. For a 10 kW system at this stage, this adds a battery cost (net procurement price) of Euro 1.600 plus the price of the fuel cell generator. Thus, it moves the break-even point further up the line by another 1 hour.

On top of this, it is a weak sales argument that we still need to employ a large battery installation, since the idea was to eliminate/replace the large battery package.

The present state of the start-up time is due to other development priorities. Basically, nothing indicates that we cannot achieve the target specification of 5 minutes' start-up time at a later stage.

There are several means to pursue in terms of reaching a shorter start-up time – like

- Pre-heating of the generator while in standby
- Increased heating power capacity (burner).

From a road map point of view, this should happen at the same time as achieving a more industrial/competitive price per kW.

Moving away from batteries can cause friction with traditional UPS suppliers

Many of the value-added-resellers do have a very strong business today in selling, maintaining and substituting batteries. This is an area where they have core expertise – and it is a substantial cash cow.

Consequently, some of them are not immediately motivated to leave this battery business.

On the other hand

- Batteries – especially in extended runtime applications – do exhibit high cost as well as a reputation of a visible impact on the system uptime (downtime, service cost, even fire)

- The battery market is presently under heavy pressure, thereby reducing the attractiveness of that part of the business ("low cost china batteries", large manufacturers selling direct to the "low hanging fruits" segments, some suppliers selling below cost for a period of time).

UPS field data to support our trustworthiness

Some end users don't like to be "first movers". They will ask for reference installations and performance statistics.

Fuel cells are based on radically new technology, so this matter must be addressed in a professional way.

Note: LeanEco is per 2016 approaching 10 years of accumulated field operation time of the power modules – still with no errors encountered. This is an unusually high reliability performance.

Market experiences

LeanEco has been approaching a number of value-added-resellers in e.g. Germany since 2015. Learnings relevant to this project are

- The German market is substantially larger than Denmark – meaning
  - Many and frequent opportunities at each reseller
  - The resellers are large and very experienced
- The German market is substantially more mature in terms of adopting professional UPS solutions for mission critical applications
  - High awareness
  - A more determined approach by the end users: They plan for it, they budget for it, and they do it
  - In general, quality is of major importance and European manufacturing is a selling point (some time it is a condition)
  - Price has normally not highest priority
  - A clear tendency towards decentral installations (i.e. small units placed locally near the applications – instead of large central installations)
- There is a substantially larger demand for extended runtime like
  - Typically, 2-8 hours of runtime
  - Battery-based – and the reseller expertise in batteries is very high.

In the hospital segment, Denmark tends to still go for large centralised solutions (MW size), where only diesel generators are feasible. This may be due to the organisational challenges and old traditions, since many arguments (and users) speak in favour of smaller, decentralised UPS solutions:

- Less cost of cabling around in the building (only one type of power distribution)
- Local tailoring of the premium power solution to local demand
- Easy to change when a new equipment is adopted (e.g. a new scanner)
- Easy and uncomplicated to relocate among departments

- Uncomplicated to adopt new buildings or to move to new buildings.

In Germany, the response is: "We also had centralised UPS solutions, but since 2000 they only make decentralised solutions".

Assuming that Denmark is lagging somewhat behind in the evolution, this could indicate that we will start to see growing opportunities for decentralised UPS solutions in a size where fuel cells can do the job – where the demand is present.

Development results

Development of the Fuel Cell Generator

The actual fuel cell development by SerEnergy was taking place in parallel EUDP project.

In this project, it was decided to change from an early baseline into a new baseline of the fuel cell basic engine, even though the consequence was a major delay of the project. This description comprises the latest baseline, the AluCore baseline.

The fuel cell power generator module

The technology development progressed well in the parallel project and more than 15,000 hours of operation was demonstrated on a single stack and more than 1600 hours on a methanol fuelled fuel cell (stack and reformer).

The project has targeted the development of a 5 kW modular Methanol reforming Fuel Cell system. First starting with an electrical heated system as generation one and then pursuing a second generation that was Methanol heated by means of a built-in burner solution.

The reliability of the systems starting and operation was one of the key challenges, but it was demonstrated that the system was stable and reliable. As this development proceeded, other issues appeared.

Figure 1: H3-5000 - 5kW module complete, no external cooling

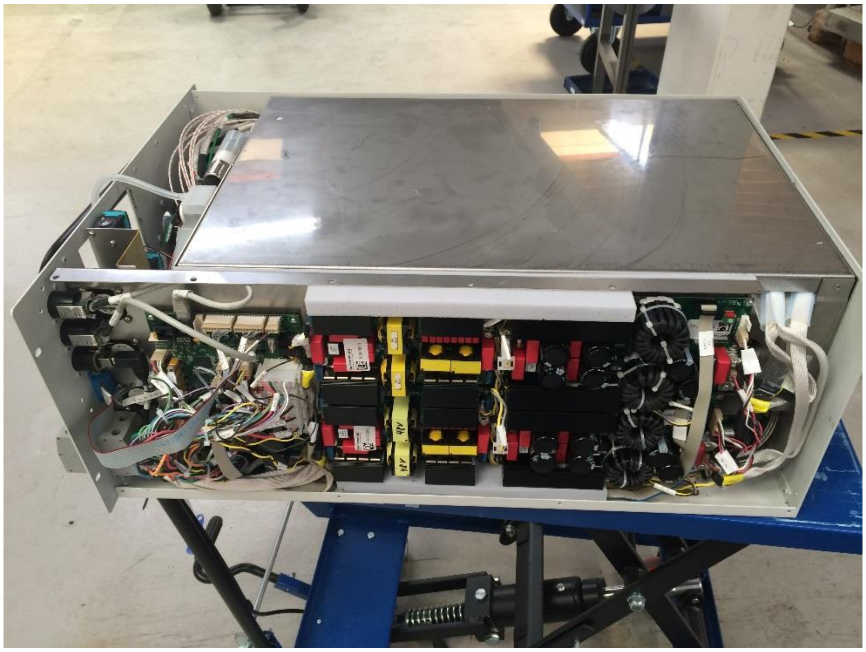


Figure 2: Power electronic + control board, side and top unmounted

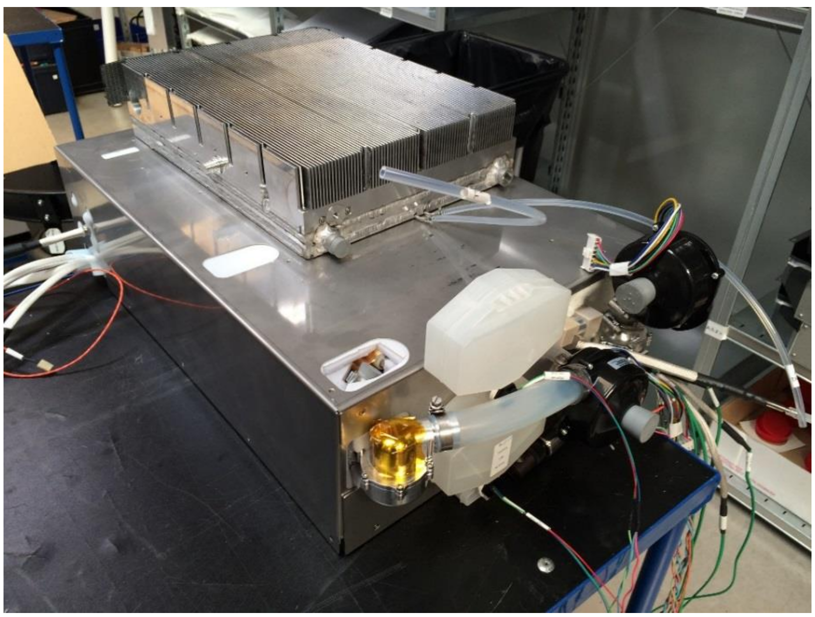


Figure 3: inner casing and cooling unit taken out, upside down.

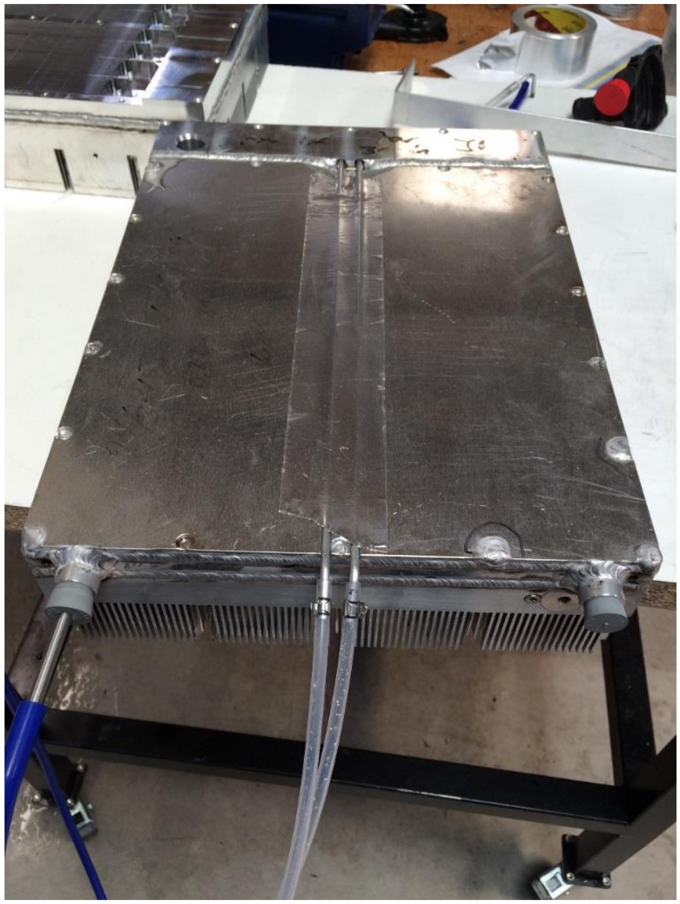


Figure 4: Cooling unit separated, manually welded, pressure test.

Figure 4 is a picture of the cooling unit hand welded together to avoid leakages (that turned out to be a major problem). This welding is very time consuming and it is not a trivial task.

A new generation of the heat exchanger (offering an easier welding process) was implemented in the manufacturing baseline and product line.

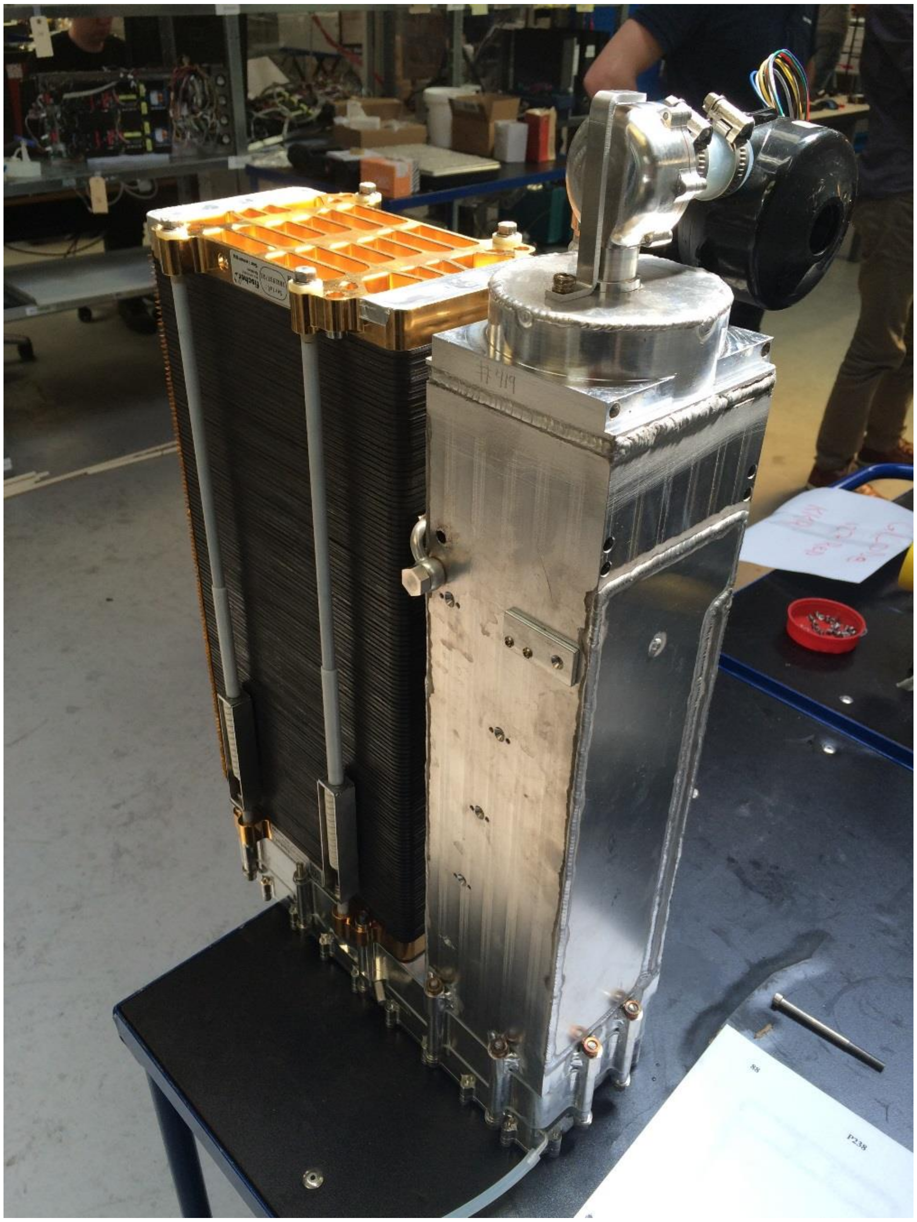


Figure 5: Inside inner casing. Stack, Alucore and reformer with burner (New generation).

Figure 6: Alucore, Reformer and burner without stack.

Open issues that were dealt with along the project were:

- Reduction of Startup time
- Cleaner exhaust (bring down Methanol and formaldehyde contents, especially in the start-up phase)
- Production maturing: New heat exchanger, new burner design, component sourcing
- Support effort in accordance with increasing amount of shipped/installed modules
- Different interfaces to module
  - SNMP (finalized before summer vacation)
  - CAN Open interface
- All parts around the fuel cell module
  - Various fuel tank solutions
  - Rules and regulations/safety.

The control interface between the UPS system and the Fuel Cell System was developed to handle

- Status information
- Start and stop commands.

Control loops for controlling currents and voltages during operation were implemented as part of the UPS system.

A 5 kW fuel cell generator with on-board methanol reformer was manufactured and delivered to the project.

Development of the UPS subsystem

The UPS system was originally developed in a former EUDP project.

Key tasks of this part of the project were

- System design with focus on extended runtime operation based on fuel cell generator modules
- Control interface between fuel cell power module and UPS system
  - User interface (configurator)
  - Start/stop procedure (autonomous)
  - Control loops for parallel operation on the Battery Bus (current, voltages)
- Physical interface
  - Mechanical design to support integration of the Fuel Cell power module into the UPS unit
- Manufacturing of a system prototype
- Maturing of the UPS design for deployment of system units on a number of customer sites
- Find customers that are willing to procure a unit and host it in a real application (deployment).

Besides, a number of parallel technical matters were solved in the project like

- Power converter control loops: The control loops were redesigned such that the load sharing among power modules became stable and robust
- The EMC performance was improved
- A large variety of UPS module configurations were tested in order to support a Configure-to-Order approach – including parallel operation of up to nine power modules
- The robustness of each power converter module was elevated by implementing fire different layers of protection
- We decided to switch to another electronics manufacturer due to cost and procurement competence issues.

Manufacturing of the UPS

The market continuously backs up our decision to keep manufacturing in Denmark. From several German resellers we even learned that Far East manufacturing was unacceptable.

A “made in Denmark”-approach requires

- A close cooperation based on traditional Danish values and trust – this saves money

- Agility – adequate priority and on-time delivery
- High-end quality
- Flexibility – being able to make use of proximity and close cooperation.

We found a supplier where such requirements appeared to be fulfilled.

System integration and test

The system integration of the two subsystems was a great success, well sought for after many months of project work.

- Key results when operating:
  - Fuel cell output power: 5.44 kW (DC, net power) (sufficient to deliver 5 kW AC out of the UPS)
  - Stable operation and stable control loops
  - No problems encountered
- Issues
  - Start-up duration is 50-60 minutes – must be lowered to say 5 minutes or less in order to make a feasible product
  - Not tested: More than one unit in parallel.

Figure 7. The UPS power system with integrated fuel cell module. The Methanol fuel tank is placed at the floor.

Figure 8. Power system. The battery system is placed in the bottom of the rack (offers 10 kW@15 minutes, 20 kW@6 minutes).

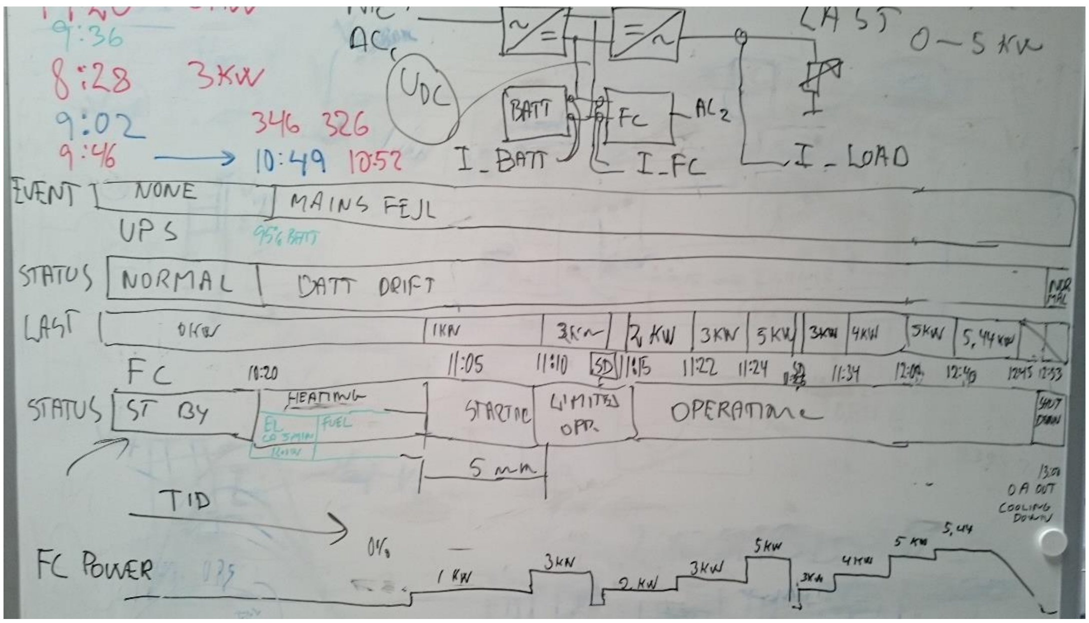


Figure 9. The start-up scheme as originally registered at the first test.

Deployment phase

The start-up duration issue indicates that the technology is not yet ready for the actual application. Consequently, neither resellers nor end users showed interest to install and test the system.

Accordingly, it was decided to reduce the deployment activities to project internal sites.

Those sites were

Site ID	Site description	Purpose
Site 1	LeanEco Lab, Kolding	Developments, tests
Site 2	EnergiMidt, Silkeborg	Experience with installation and operation on a real site

Site 3	SerEnergy, Aalborg	Laboratory tests at Serenergy (fuel cell, only)

The tests of unit 3 will be based on test objectives specified by the project partners (not included in this report).

The key experiences of the deployment at sites 1 and 2 are outlined by the nest section.

Learning from deployment activities

Description

The system that was installed was constituted by the following items:

- UPS power system – indoor placement and equipped with
  - 2 x 10 kW power modules (forming a 10 kW un-interruptible power supply)
  - A single no-break power output connected to room applications electrical panel (3 x 230 VAC, up to 16A per phase (10 kW load))
  - Battery Magazine
    - Battery control interface
    - 8 battery cartridges each with 8 x 7 Ah / 12 V capacity
  - Fuel Cell power generator unit
    - >5 kW power capacity
- A Methanol Fuel tank (palette container) – outdoor placement.

The system loads were non-critical applications like

- Room light
- Room ventilation
- Workshop tools etc.

End user perception and feedback

In general, people were very pleased by the technology and the scope of it – like clean energy, no diesel generators, etc.

Also, there was some indications of "lack of confidence" related to safety aspects and building installation aspects. Key reason for this was the lack of a clear documentation stating

- Which rules apply?
- How do we state compliance to those rules?

This mainly relates to the use of Methanol Fuel.

The UPS (power system) has been developed according to established standard: IEC 62040 – parts 1/2/3. This standard comprises the rules set out by the EU Directives

- Low Voltage Directive (safety)
- EMC Directive (noise, disturbances, compatibility with Grid etc.).

In terms of safety, the IEC standard has lead to solutions in those three areas:

- Installation and Operating Manual (including operators, access rights, etc.)
- Physical design and construction
- Labels on the product.

Documentation

For a commercial product the following documentation is recommended:

- Rules and regulations overview
  - A list of applicable rules and regulations for the actual location
- Compliance statements
  - Certificate of conformance to applicable rules and regulations
- Insurance aspects
  - Short description of how to cope with insurance

Legal matters

Insurance did create some discussion. Consulting relevant insurance companies lead to this brief outline:

- Safety hazards related to the product is covered by the supplier's product responsibility insurance
- Installation hazards are covered by involved contractor's insurances and warranties
- Fire hazards and other building hazards: Are covered by the end user's building insurance.

It is recommended that the end user's building insurance company is informed in order to be sure that the insurance covering remains effective.

Handling non-approved products (R&D prototypes)

The installation and use of prototypes on a real end user site may require that the end user signs a document where he accepts the risks and uncertainties associated with the product.

During this process, the end user is likely to ask for documentation that describes what rules that apply and to what extent the product is expected to fulfil such rules and regulations, including how far the development has proceeded in terms of tests and verifications (i.e. what has been done versus what has not yet been done).

Local contractors

Local contractors are likely to take on tasks that are outside their normal experience and competencies – some of them are positively interested to participate in order to obtain such experiences.

Their feedback during the process is important in areas like

- Product design

- Cost reductions
- Safety
- Service and maintenance.

This site involved

- Electricians (placing, cabling)
- End user's inhouse facility people (placing, access, fire)
- End user's IT people (IT safety, practical connection to local area network).

Physical environment (placing, access, interfaces and connections)

The site was chosen in order to

Minimize fire risks and consequences

- 1-2 people at a location isolated from the end user's main building
- Operation only when people were present.

The Fuel Storage was placed outside the building

- Easy access for re-fueling
- Best situation to cope with fire (not in the proximity of fuel cell and electrical hardware, easy and fast removal, dilution with water).

Operational experiences (noise, heat etc.)

The acoustic noise of the system is very low and did not lead to any issues at the selected location (work shop).

The waste heat from the system was hardly noticeable since the room was

- Well ventilated and
- Rather large (150-200 square meters).

Fuel Cell exhaust was lead outside the room (exhaust pipes through the wall).

People and access to the facility

The following people had access to the location:

- End user's employes with authorization to enter the room/work in the room
- Project participants and relevant contractors.

System performance

System integration and control

The system performed well and according to expectations.

It is always an important part of the verification to leave control and operation to a third party. In this project, it was judged necessary to adjust some of the control loops/user interfaces (software modifications).

The system was fitted with an autonomous self-start capability in order to facilitate use and operation.

Training and documentation

On-site people were trained in starting and stopping the system (that took place on a daily basis).

System technical issue list (important matters to be fixed)

A few important technical issues were dealt with before deployment/installation – like

- Control loops stability
- Self-start robustness (a list of potential issues during starting procedure was created in order to – at a later stage – make the self-start function robust and autonomous under most conditions).

Ideas for the product road map and for product development phase

All experiences and potential issues were listed as a basis for future tasks and developments:

- Robustness
    - Ensure that the system can cope with a wide range of events, faults and situations – without the need of supplier/engineer/service people interference
    - This is especially relevant for the fuel cell self-start procedure
- Standard interface solutions (fuel supply, exhaust) and associated standard documentation for contractors
- UPS control interface
    - Communication must be encrypted (to allow for remote communication external to the site and also to eliminate discussion with end user IT people)
    - The system's logging of data, events and faults
        - Must be enhanced
        - Log data must relate to text information and explanations that are unambiguous and easy to understand
        - Log data must comprise individual time stamps giving the real time of the event.

Project Conclusions

The UPS development was carried out successfully to a level that could support selling of units, delivering of (limited numbers) of units to real customer sites.

The fuel cell starting time was outside expected specifications to an extent that was inhibitive for the original sales messaging:

The startup duration of approximately 1 hour required that meanwhile, the UPS was powered from a battery with a runtime of 1 hour.

The consequence of this was an offset of the benefits of using fuel cell for extended runtime. This made it cumbersome to convince traditional customers to buy and install the units as part of the deployment phase.

There were known solutions of how to pursue a lower the startup duration of the fuel cell – like

- Active heating (enhanced burner capacity)
- Pre-heating of the fuel cell unit (keeping it warm when not in use).

The duration of such developments was estimated to last for approximately two years.

However, during the project it was decided not to pursue an immediate reduction of the fuel cell startup duration. The reason was that it would last approximately 5 years or more to meet the sales price of the fuel cell technology required for UPS applications.

Accordingly, the specific development activities to increase startup duration were given less priority and accordingly postponed say 3 years or more.

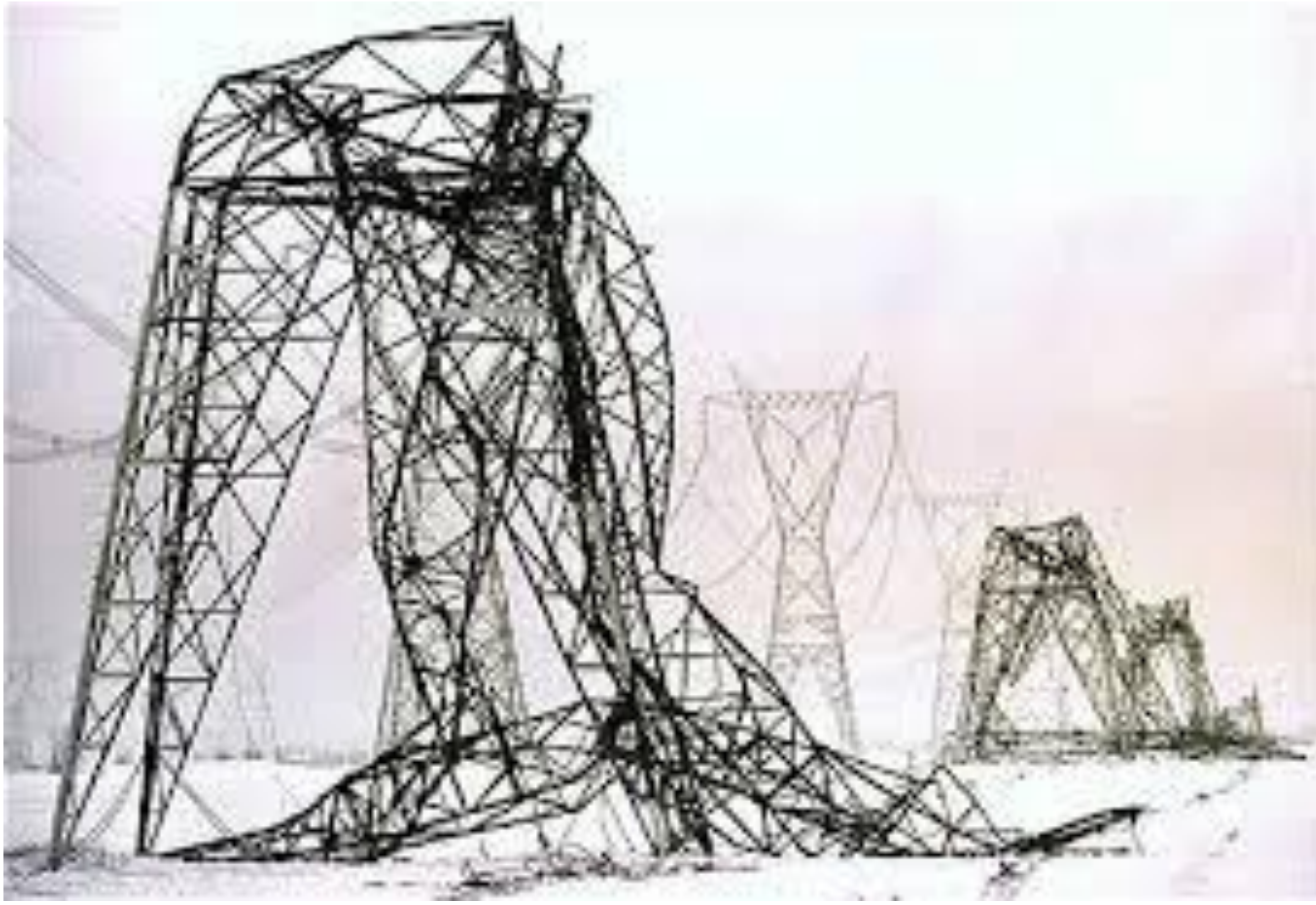
This project therefore focused on a limited deployment activity. A single unit was successfully installed and operated on an end user site.

The project outcome has been very valuable, although the road map still asks for a critical performance improvement on the high temperature PEM fuel cell power generator: The startup duration must be reduced to a few minutes in order to become able to reduce the battery bank or even to replace the batteries by super capacitors (that could lead to substantial reduction in service and maintenance costs).

End of report

Background information

Annex A: Grid Outages – how well is the power grid doing?



Presently, an average end user in the Danish power grid will see accumulated outages every year in the order of 23 minutes, but this figure varies substantially from region to region. However, this figure denotes the downtime at power plant level (High Voltage) and not at user level of the power distribution.

Very large electrical distribution networks (like in Australia or US) typically offer substantially more downtime since issues along the grid lines are more likely to appear (e.g. thunderstorms and other challenging whether conditions).

Availability is the term used to describe the average downtime.

Total downtime per year	Availability
36.5 days	1 nine (90%)
3.6 days	2 nines (99%)
8.7 hours	3 nines (99.9%)
52 minutes	4 nines (99.99%)
5 minutes	5 nines (99.999%)
30 seconds	6 nines (99.9999%)
3 seconds	7 nines (99.99999%)
0.3 seconds	8 nines (99.999999%)

Figur 1. Availability level and the associated annual downtime.

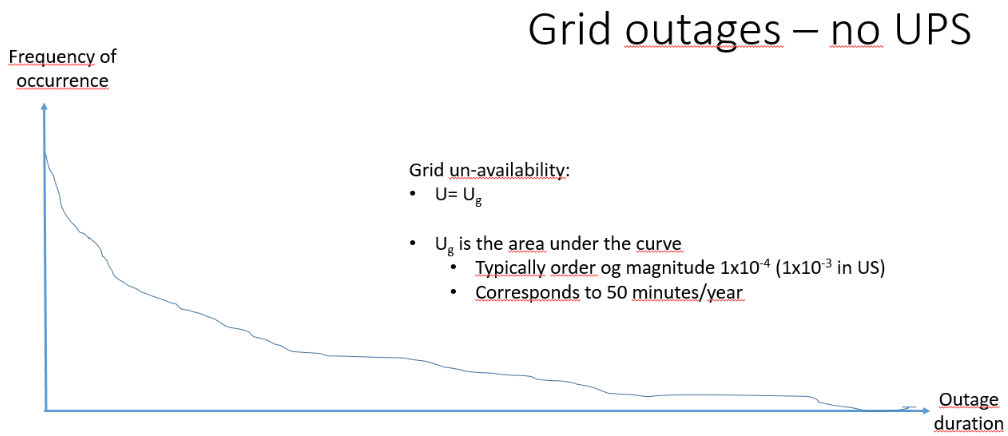
At user (Low Voltage) level, the grid power availability is somewhat lower, as there are many local factors that influence the resulting availability locally at the end user site:

- The general evolution in grid load versus capacity
- The quality of the local distribution (transformers, cables, air or ground cables…)
- The local load behaviour versus grid capacity
- Construction work (cutting cables)
- Maintenance of the grid (cables, switches…)
- Weather and climate (hurricanes, thunderstorms, flooding …)
- Own in-house installations (faults, fuses, machines, changes, growth, installation of new equipment…)
- Neighbouring installations (faults, fuses, machines, changes, growth, new equipment…).

The grid outages are often described by means of a statistic distribution model that comprises elements like

- Short outages occur rather frequent like
  - Outages with a duration of milliseconds-to-seconds could take place on a weekly basis
  - Blowing a fuse in case of a short circuit typically lasts around 200 ms. While this is on-going, the voltage is close to zero (short cut)
- Long outages occur rarely
  - Example: Outages with a duration of 1 hour or more are seen maybe once every 3-5 years.

This statistical behaviour is described by a statistical model (distribution).



Figur 2. A qualitative outline of how a grid outage distribution could look like.

The un-availability, U_{grid}, of the grid is given by the area under the distribution curve. The grid availability is given by

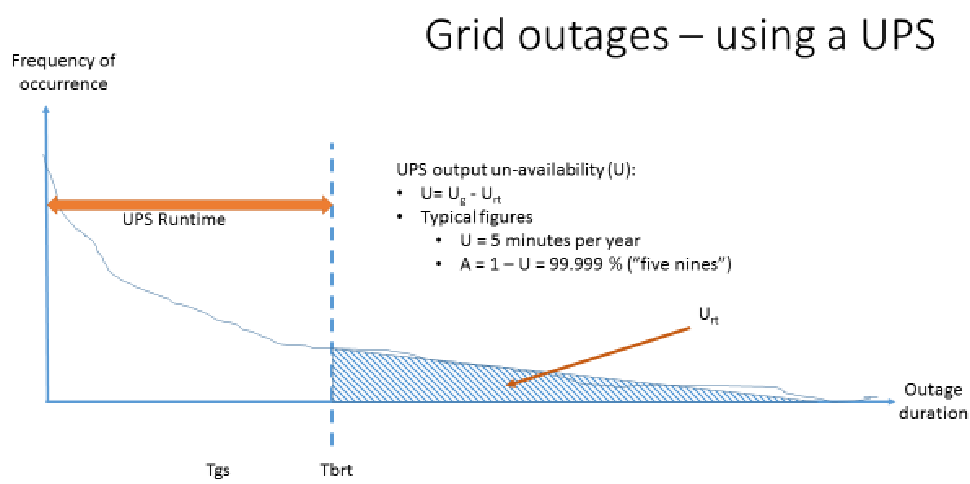
$$A_{grid} = 1 - U_{grid}$$

Example: An unavailability of 0.001 means that the grid is unavailable 8.7 hours per year ("i.e. the grid availability is 99.9% or "three nines" – see figure 1). (PS: This is a rather normal figure in e.g. USA).

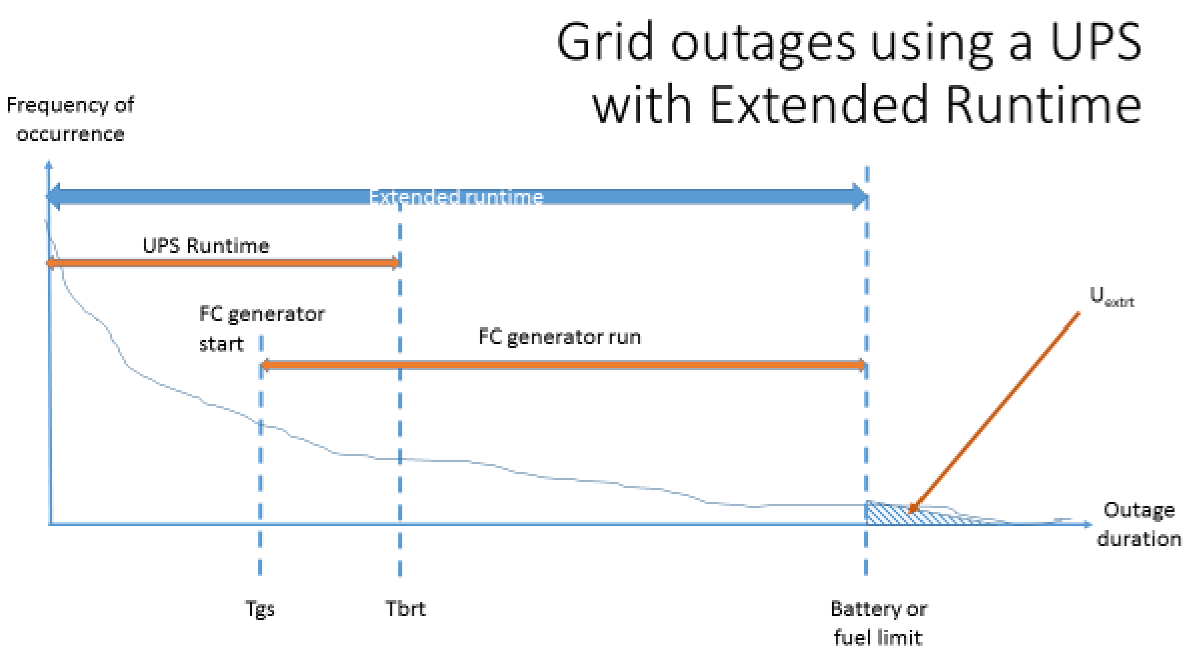
What is the idea of a UPS system?

The UPS is capable of bridging all power outages with a duration that does not exceed the Runtime of the UPS. For enhanced protection, the UPS runtime is enhanced by attaching so-called extended runtime.

Now – with a UPS system in front of the application – the unavailability is now limited to all outages that exceed the UPS runtime. I.e., it is given by the area under the distribution curve from the point "runtime" and upwards. This is radically improved compared to the grid availability itself.



Figur 3. The idea of introducing a UPS is to cover all outages below a given duration, thereby increasing the resulting power availability.



Figur 4. Same as for Figure 3, but illustrating the effect of further enhancing the runtime of the system.

Basically, an Un-interruptible Power Supply (UPS) system can perform at least two tasks

- It bridges power outages, such that applications do not suffer from loss of power

  - This is done by means of an energy storage, such that the UPS can sustain the output power even when there is no input power – at least while there is energy in the storage
- Furthermore, it protects the applications against disturbances on the power grid (like overvoltage, glitches, undervoltage, surge, etc.). Disturbances that are often the root cause of destroying hardware like computers and data storage.

Downtime is associated with a certain cost. The cost-of-downtime can be split into three types

1. Immediate loss due to the interrupt event itself (even very short interrupts can have these effects)
   a. Loss of data (corruption of databases)
   b. Termination of or loss of control in processes and services (traffic control, manufacturing management, CNC machines, conveyer belts, destruction of manufacturing goods and items)
   c. Unable to restart software processes that were halted
   d. Loss of un-saved work and data
   e. Safety hazards
   f. Loss of control of financial transactions (requires audits and/or formal approval)
2. Loss that is related to the duration of the downtime
   a. Loss of revenue (e.g. in a WEB-shop, or because the company cannot take in new orders or ship goods)
   b. Loss of customers (e.g. the company's mail or web site is down)
   c. Loss of work (people that are sent home because Axapta/SAP is nor working)
   d. Loss of goods (e.g. frozen biological material and samples)
   e. Safety hazards (lifts, security, gates, cooling pumps, water evacuation pumps…)
   f. Inconvenience (climate control)
3. Indirect losses
   a. Management resources and meetings
   b. Efforts to keep unhappy customers
   c. Consultancy cost to find/re-establish data and repair of data bases (weeks to months)
   d. Consultancy cost to restart software applications (may take weeks)
   e. Law suits
   f. Demotivation of employees
   g. Non-compliance with corporate values
   h. Losses associated with overheating, flooding and humidity (lifetime, furniture, equipment, building…).

Notes:

- Many of the loss effects incurred under section 1 can result in important long term effects even though the disturbance is very short.
- The indirect losses alone can be orders of magnitudes larger than the cost of a state-of-the-art UPS solution.

The cure:

- Losses of type 1: A no-break (UPS) solution will reduce the probability of this event radically – extended runtime will furthermore reduce the probability of occurrence
- Losses of type 2: A backup solution (with extended runtime) will reduce such losses
    - A no-break solution is the preferred solution, as many of the Type 1 effects also tend to create some of the long-term effects
    - However: Lifts, water pumps, refrigerators, etc. could do with a backup solution (i.e. a generator-type of solution, no-break may not be required).

Note: LeanEco's LivingPower™ solution can be configured to do no-break as well as backup – or a blend of these.

The un-awareness of these risks and costs is significant especially in so-called industrial countries, but awareness is rapidly increasing as terrifying cases from the real life are being published more and more often.

The right step for any enterprise or organisation would be to implement a so-called "Cost of downtime analysis". This will determine the risk and consequences of power outages for the actual business.