Final report

1. Project details

Project title	Crosscut
File no.	64016-0011
Name of the funding scheme	EUDP
Project managing company / institution	Ballard Power Systems Europe A/S
CVR number (central business register)	30804996
Project partners	Aalborg Universitet, Stofa, Hydrogen Valley
Submission date	05 April 2022

2. Summary

The CrossCut project aim was to demonstrate how fuel cell systems in collaboration (hybridization) with renewable energy sources and with energy storage solutions can support the Danish and Global climate goals of substituting fossil energy sources and how standardization and simplification can drive down production cost.

The project Crosscut managed to reach the key objectives of:

- **Developing standards and methods for benchmarking of components and methodology for testing of components**: This objective has been reached firstly developing a new Fuel Cell DCDC topology with standard components to reduce controller and power module related faults and cost. This new topology will be used as base for a new platform to be future proof and guarantee the highest reliability. Also, a new tester for Factory Acceptance Test of the DCDC´s PCB has been developed, with standard SW and electronics. This will be used as benchmark standard for all testing procedures. Lastly, a Big Data tool has been created, to collect, filter and process all FC units in the field, for performance improvement and preventive maintenance, with the benefit of extending the fuel cell system lifetime.

- **Developing a hybridization design tool for optimized total cost of ownership (TCO)**: a web based TCO tool has been developed, and widely used, in order for the user to compare backup power solutions.

- **Demonstrating FC hybrid at end customer:** a hybrid installation has been demonstrated, with 4.5 kW fuel cell power, 9.6 kWh battery capacity, and 2.4 kW solar panels, for a site load of 7 kW. The

solution differs from the originally planned one in terms of FC and solar power installed, and therefore the results (detailed in a full TCO report) also differ from the anticipated ones, proving the installation suboptimal. The installation and the experience acquired are nonetheless valuable to critically decide over future hybrid systems.

Formålet med CrossCut projektet var at demonstrere, hvordan brændselscellesystemer koblet med produktion af grøn elektricitet og energilagering kan understøtte den globale og danske målsætning om at erstatte fossile energikilder med fornybare kilder og hvordan standardisering og forenkling kan reducere produktionsomkostninger.

Crosscut formåede at nå projektets hovedmål:

- Udvikling af standarder og metoder til benchmarking af komponenter og metode til afprøvning af komponenter: Dette mål er nået ved at udvikle en ny brændselscelle DCDC topologi med standardkomponenter med henblik på at reducere controller- og strømmodulrelaterede fejl og omkostninger. Denne nye topologi vil blive brugt som base for en ny platform, som fremtidssikker og garantere den højeste pålidelighed. Projektet har også udviklet en ny test til fabriks accept test af DCDC's PCB med standard SW og elektronik. Dette vil blive brugt som standard for alle testprocedurer i fremtiden ved Ballard. Endelig er der oprettet et Big Data-værktøj til at indsamle, filtrere og behandle alle FC-enheder i marken med fokus på forbedring af ydeevne og forebyggende vedligeholdelse og forlængelse brændselscellesystemets levetid.

- Udvikling af et hybridiseringsdesignværktøj til optimerede samlede ejeromkostninger (TCO): et webbaseret TCO-værktøj er blevet udviklet og brugt i vid udstrækning for at brugeren kan sammenligne backup-løsninger.

- Demonstration af brændselscelle-hybrid løsning hos slutkunde: En hybridinstallation er demonstreret med 4,5 kW brændselscelleeffekt, 9,6 kWh batterikapacitet og 2,4 kW solpaneler til en belastning på 7 kW. Løsningen adskiller sig fra den oprindeligt planlagte med hensyn til installeret FC og solenergi, og derfor afviger resultaterne (detaljeret i en fuldstændig TCO-rapport) også fra de forventede, hvilket viser, at installationen er suboptimal. Installationen og den erhvervede erfaring er ikke desto mindre værdifuld og afgørende i forhold til fremtidige beslutninger om hybridsystemer.

3. Project objectives

CrossCut aimed at demonstrating in real environment how fuel cell systems in collaboration with renewable energy sources and energy storage solutions can support the Danish and Global energy decarbonization, with a verification of the end-user economy (TCO).

The project focused also on the development of power management components to achieve high cost efficiency for components and system.

3.1 Developed and demonstrated technologies

3.1.1 Hybrid installation

The consortium installed and demonstrated a hybrid electric FC system with 4.5 kW fuel cell power, 9.6 kWh battery capacity, and 2.4 kW solar panels, for a site load of 7 kW.

Figure 1 – Hybrid installation Viby J

The site initially selected had a load of 4 kW and the solar cell power of 6 kW. The changes had a major impact on the solution, which is sub-optimal, how illustrated in the TCO report which also shows that the solar cell installation was financially an unprofitable decision. The TCO also investigated the possibility of installing a hybrid PV-panels, fuel cell and batteries system on an off-grid site.

3.1.2 TCO calculator

The TCO calculator tool is a web-based service used to design a backup system, and compare battery and fuel cell options, with diesel generators as well. The result is a comparison of the different options.

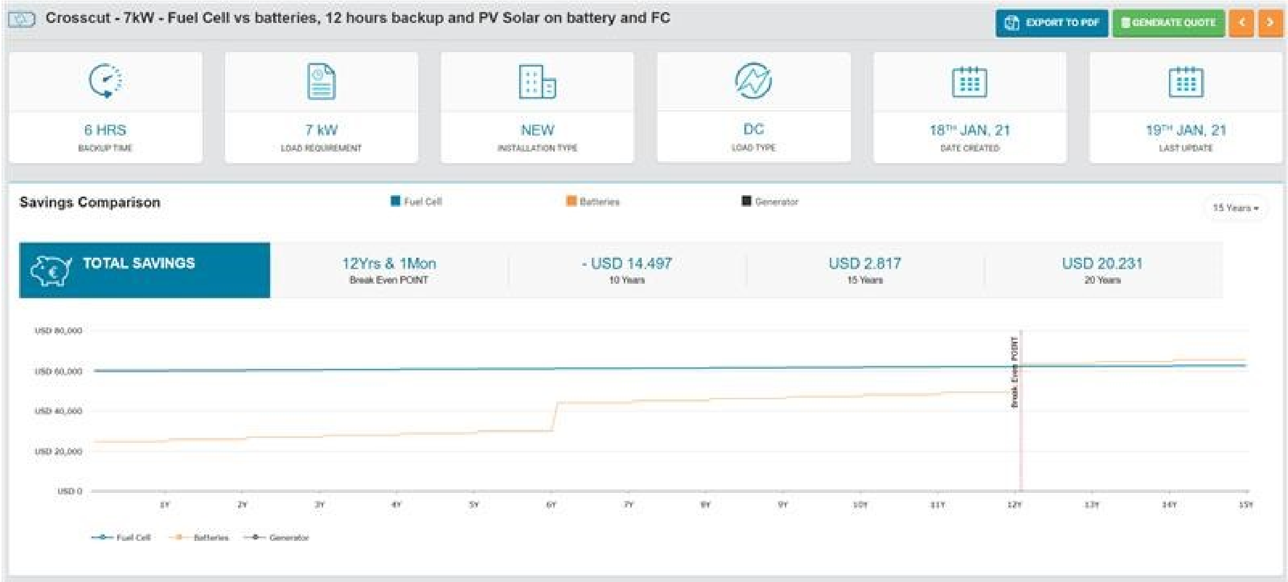


Figure 2 - TCO tool Ballard

3.1.3 Big-data software

A big-data software tool has been developed, to collect, filter and process all FC units in the field, for performance improvement and preventive maintenance.

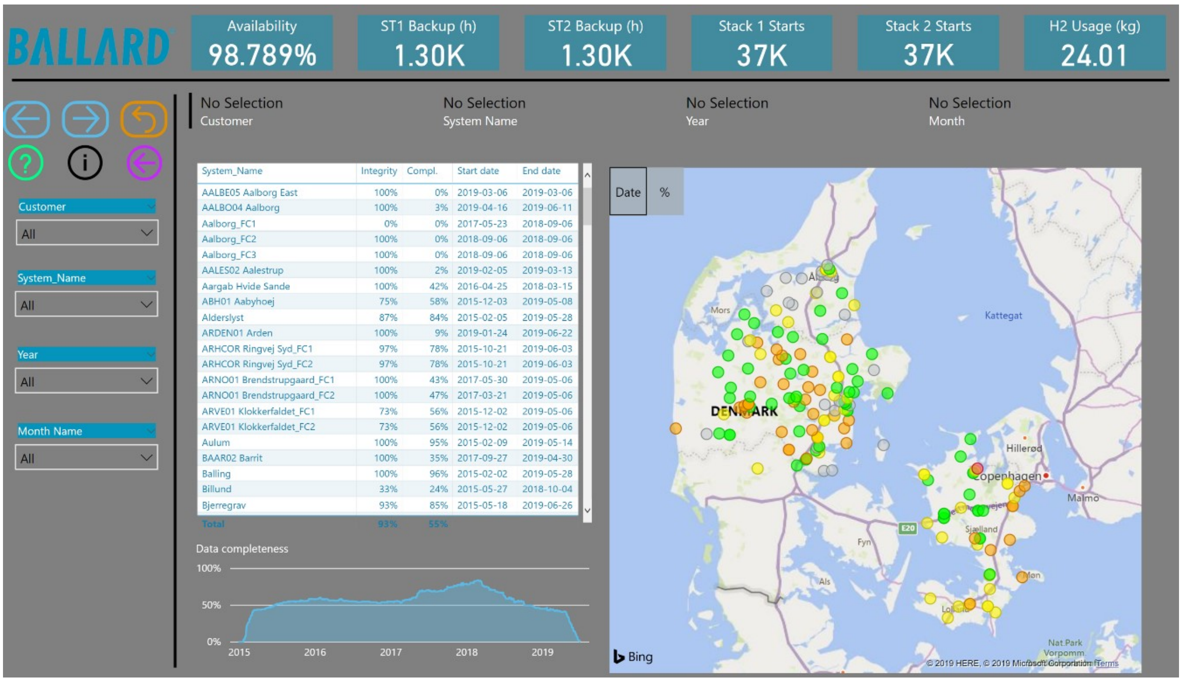


Figure 3 - Big data tool Ballard

3.1.4 DCDC converter

An evaluation of the current Ballard design showed that a replacement of the components won't make the design future-proof. An alternative design was therefore studied with the aim of making the converter simpler, cheaper to manufacture and more reliable.

A prototype dual active bridge (DAB) DCDC converter was designed and prototyped.

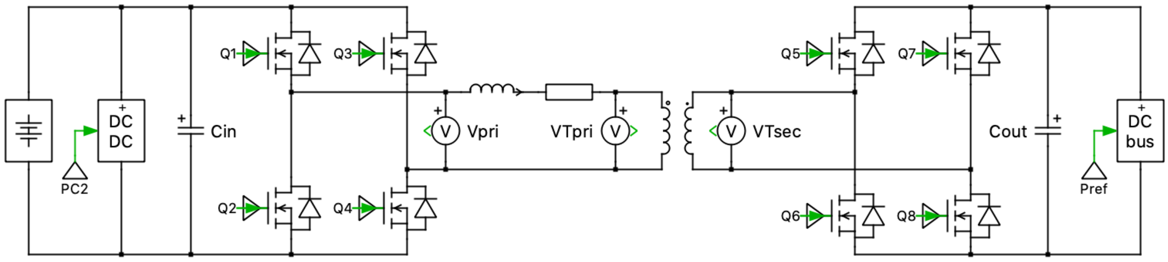


Figure 4 - Simulation model of the DAB converter.

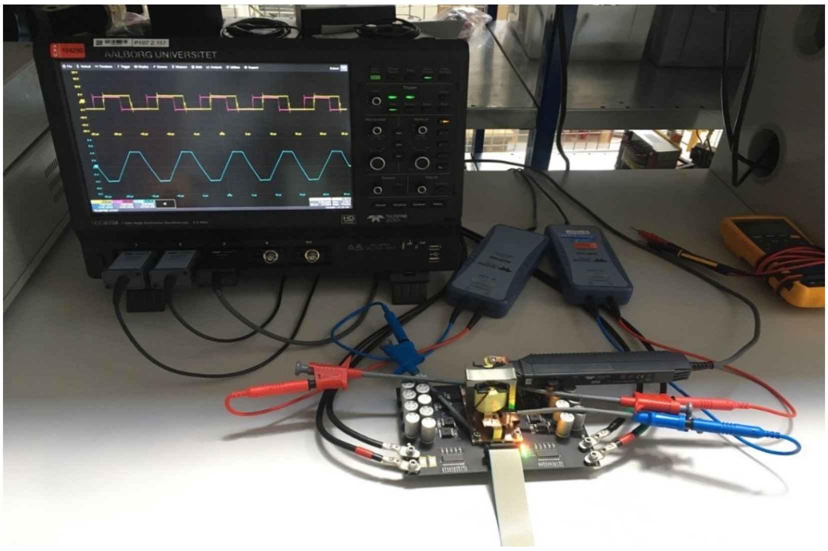


Figure 5 - DAB converter prototype

3.1.5 Factory Acceptancy Tester

A Factory Acceptance Tester (FAT) has been developed with focus on reliability and standardization to secure the quality of the DC/DC power circuit board.

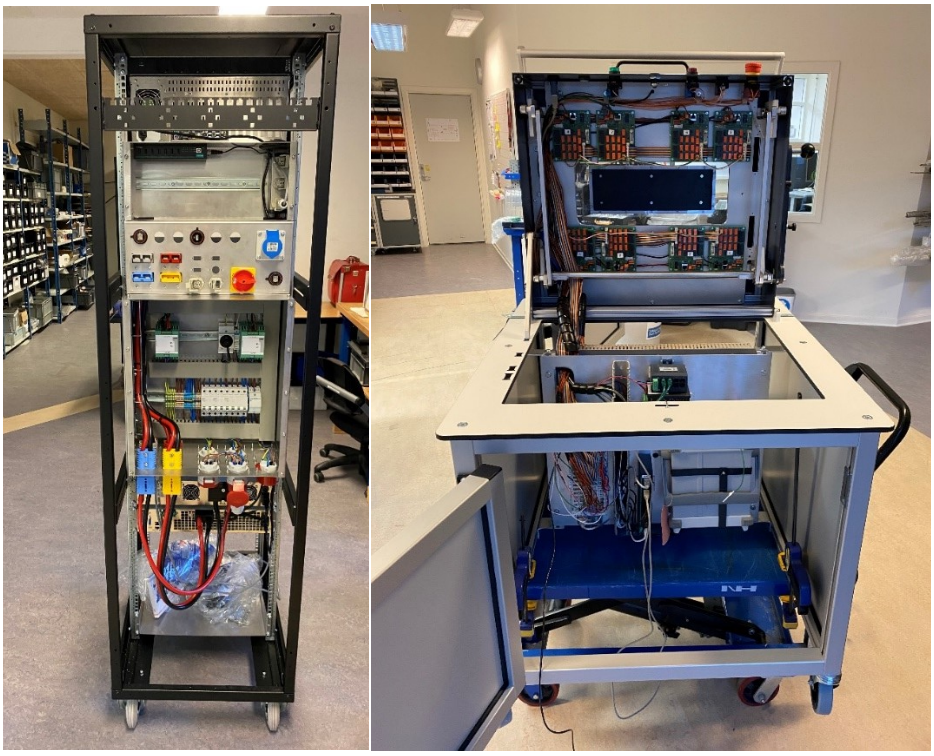


Figure 6 - DCDC PCB FAT tester

4. Project implementation

4.1 WP2 evolution

Within WP2, AAU and Ballard successfully collected all the requirements for the power management system and FC system, during several workshops, discussing the different technologies that could be integrated into a hybrid solution. Requirements from the power management system between the hybrid components and requirements for the FC system were also in focus. Figure 7 shows the result of the workshop were four types of batteries have been found suitable. The same have been done for photovoltaic solutions.

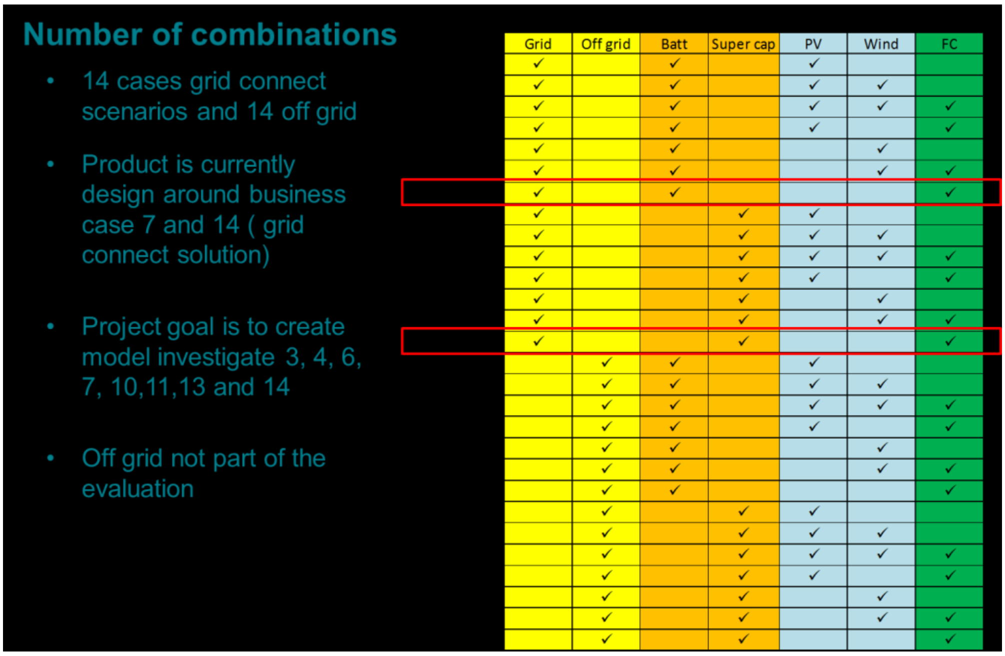
Parameter	Lead-acid	Li-ion	NiMH	Supercapacitor
Main types	Flooded, sealed, AGM	NMC, NCA, LFP, LTO, LMO, ...		Power or energy optimized
Power density	150 -180 W/kg	500 - 2000 W/kg	250 – 1000 W/kg	500–5000 W/kg
Energy density	30 - 40 Wh/kg	75–250 Wh/kg	60-120 Wh/kg	2.5–15 Wh/kg
Cell voltage	2.0V	2.0 – 3.7V	1.25V	2.7V
Response time	msec	msec	msec	msec
Round – trip efficiency	80 – 85 %	85 – 95%	ca. 70%	90 – 95%
Self-discharge	3 – 20% per month	<5% per month	30%-60% per month	up to 5% per day
Memory effect	No	No	Yes	No
Peukert coefficient	1.1 – 1.4	~1	1.1 - 1.3	~1.05
Balancing circuits	No	Yes	No	Yes
Cycle life	300 – 2000 / 80%	4000 – 16000 / 80%	180 – 2000/80%	1000000/ 80%

Figure 7 - Battery suitable for hybrid back-up solution

4.2 WP3 evolution

WP3 focused on **Hybridization design and modelling.**

The first year´s focus has been on a TCO tool, to calculate and help choose equipment and solutions that could be integrated into the hybrid solution.



Grid	Off grid	Batt	Super cap	PV	Wind	FC
✓		✓		✓		
✓		✓		✓	✓	
✓		✓		✓	✓	✓
✓		✓		✓		✓
✓		✓			✓	
✓		✓			✓	✓
✓		✓				✓
✓			✓	✓		
✓			✓	✓	✓	
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Figure 8 Hybrid combinations

The software purpose was to use the inputs gathered form the dialog between the customer and the sales person. The SW inputs are: Back up time, load profile, location, shelter size etc. The software database hold information about lifetime, performance curves, efficiency, etc. The information in the database were be supplied by BPSE and AAU for the equipment suited for the hybrid solution in this project. The software will then calculate an output of useful numbers: Refueling intervals, expected system lifetime, CAPEX, OPEX, TCO and Co2 reduction.

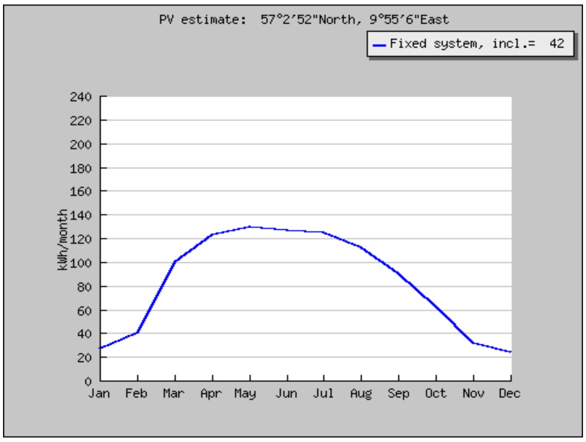


Figure 9 Average monthly electricity production of a 1 kWp crystalline PV system located in Aalborg, facing South. Calculation by PVGIS.

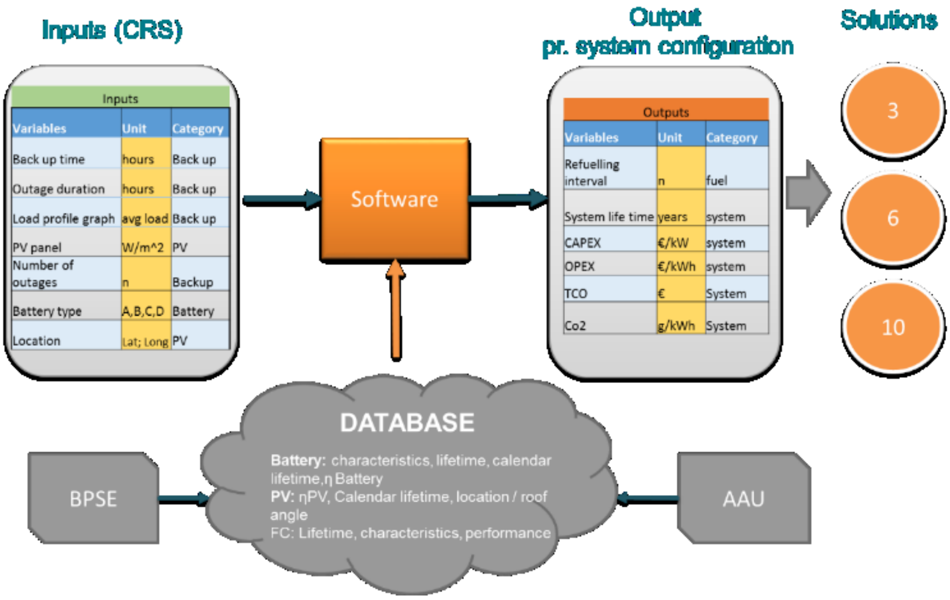


Figure 10 Software design to calculate TCO, etc.

Later during the project further work has been done with the tool for calculating TCO on a hybrid solution. The tool can currently calculate TCO on two battery solutions. Solar cells are being implemented as well as a calculation of CO2 savings.Furthermore, in the scope of WP3 AAU and BPSE performed an extensive work to systematize field data from a high number of Fuel Cell systems. This led to the creation of a big data tool, to collect, filter and process all FC units in the field, for performance improvement and preventive maintenance.

The work started identifying methods that will help determine the condition of a given system and be able to estimate the remaining life.

The tool has been used initially to collect data on 50 sites.

The work has then been to define ways in which the data points can be analyzed. One of the methods is to measure the energy the system produces during the start-up period "boost period". The theory is that the more energy the fuel cell can produce in the boost period, the better "state" it is in. Figure 3 shows how the energy is calculated in a specific area "boost period". It is important that it is the same area because it is calculated for all systems otherwise comparison between the systems will not be possible.

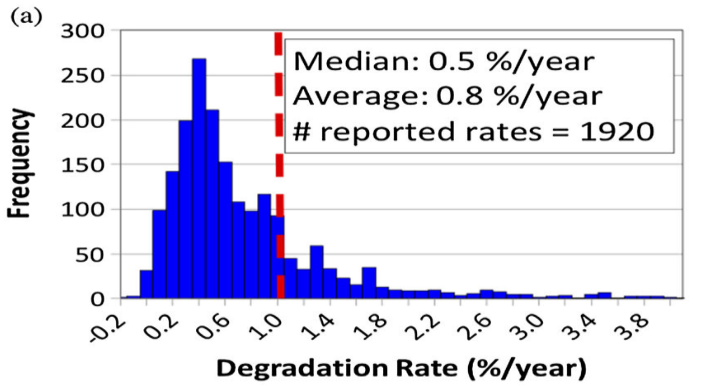
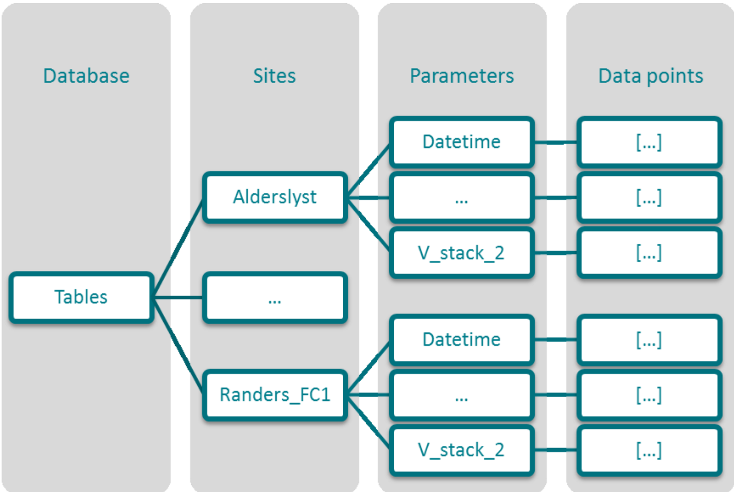


Figure 11 - Histogram of reported degradation rates globally for all PV technologies [1].



Figur 12 - Data structure

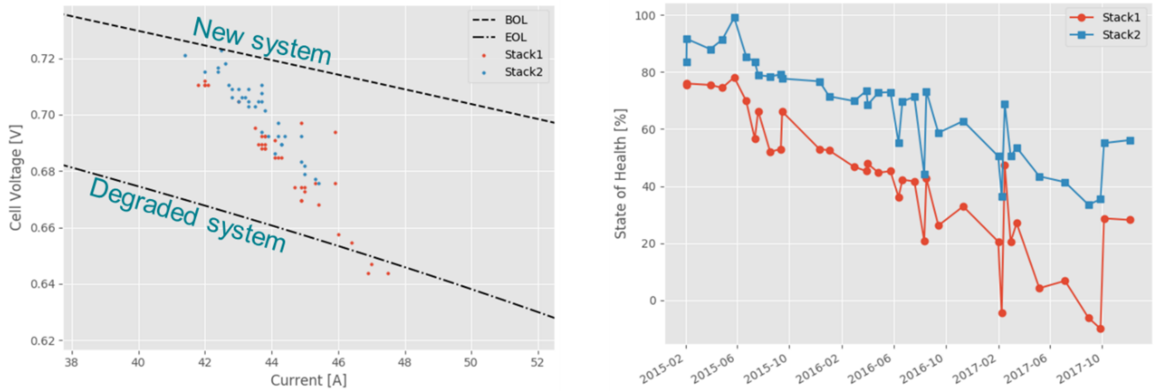


Figure13 - Fuel cell spænding i forhold til strøm (venstre) / State of Health i % over tid (højre)

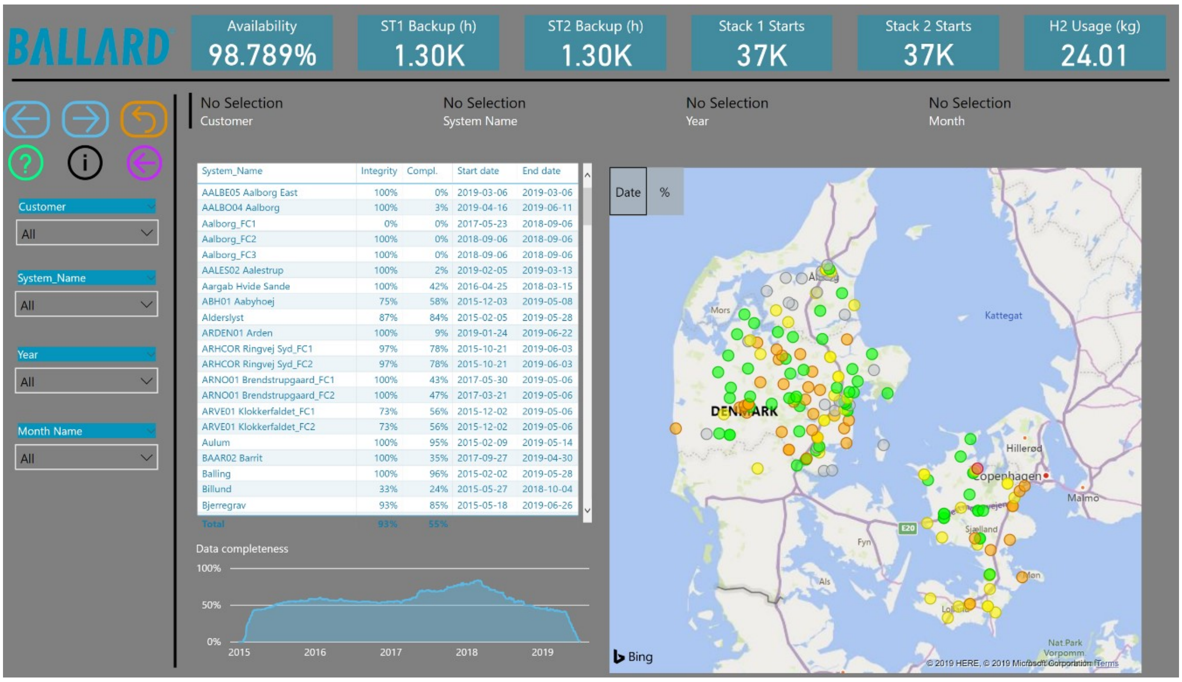
Another parameter that has been looked at is the voltage the system is able to deliver at the end of a test. This is one of the more common methods of detecting fuel cell stacks degradation. Figure 5 shows how the voltage from the fuel cell stack decreases over time.

In the period following the creation of the tool, the activities have mainly consisted of detecting and understanding the outcomes that are found in the prepared key performance indicators (KPIs). Two approaches are being used to address this. The first approach was to make an estimate of the state of health (SOH), and this has been further processed so that a prediction of SOH can be given. The second method analyzed the underlying system data such as voltage, current and temperature. Data from both methods are used in a Recurrent Neural Network (RNN) to create a system model.

This work has contributed to the following 3 articles.

Submitted papers

1. **Detecting performance outliers in fuel cell backup power systems**
   - S. H. Sønderskov, D. Rasmussen, J. Ilsøe, D. Blom-Hansen and S. Munk-Nielsen. Submitted to *21st European Conference on Power Electronics and Applications (EPE'19 ECCE Europe)*, 2019. Accepted.
2. **State of Health Estimation and Prediction of Fuel Cell Stacks in Backup Power Systems**
   - S. H. Sønderskov, J. Ilsøe, D. Rasmussen, D. Blom-Hansen and S. Munk-Nielsen. Submitted *to IEEE Transactions on Industrial Electronics*. 2019.
3. **Predicting Performance Indicators of Fuel Cell Stacks in Backup Power Systems**
   - S. H. Sønderskov, J. Ilsøe, D. Rasmussen, D. Blom-Hansen and S. Munk-Nielsen. To be submitted to *Elsevier Journal of Power Sources*. 2019.



Figur 14 Big data tool Ballard

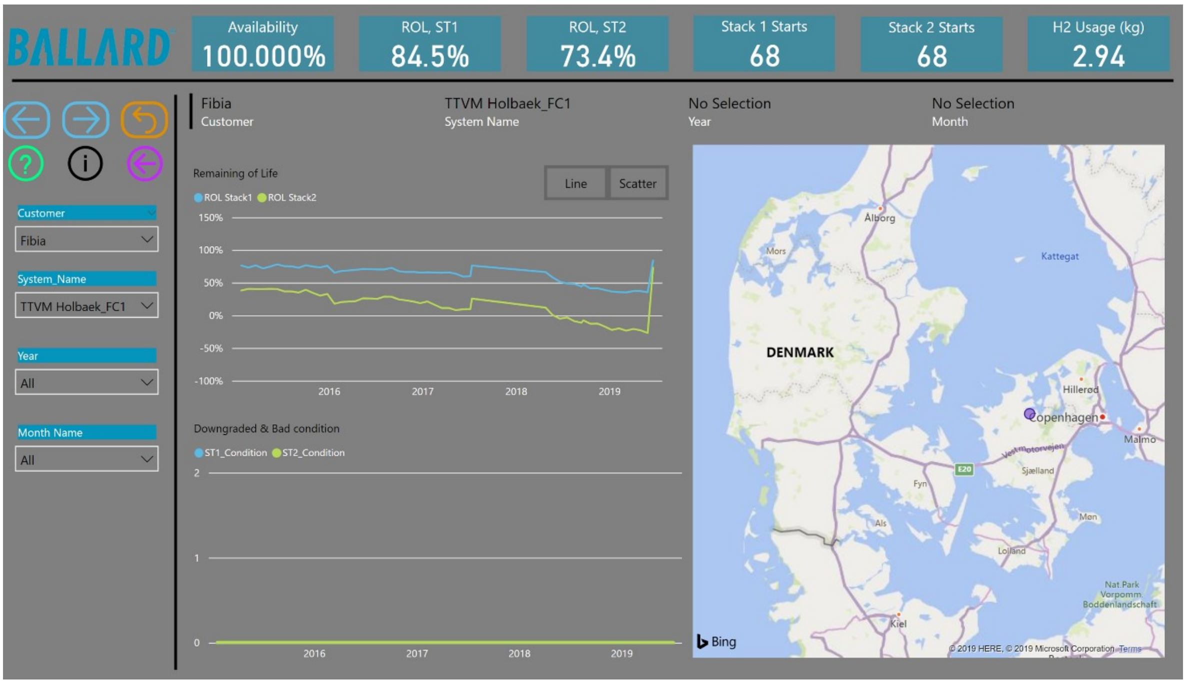


Figure 15 - Big data tool remaining of life graph

Figure 14 and Figure 15 are two examples of the data that can now be easily read from the systems in the field. Figure 14 shows an overview of all systems. Things like availability and number of backups can now be read across all systems. Different filters can be turned on so that specific data can be read out. Figure 15 shows an example of the data processing and KPI generation that has been developed in the project. The graph "remaining of life" shows how much life is left in the system. In this case on the fuel cell stacks.

Once the data models that will help predict the graph have been further matured, they will also be implemented so that preventive maintenance can ensure high availability and help extend the life of the systems further.

In addition to the big data tool, Ballard has also developed a small tool that can look up individual systems in the database and generate graphs that can help with troubleshooting and further analysis of specific data sets from the systems.

Ballard has also improved the database for the KPI handling. It is now possible to set up systems in the field and have a fleet management overview of all systems in the field.

4.3 WP4 evolution

WP4 consisted of two parallel activities: A) develop a cost optimized generic Fuel cell controller platform suitable for several hybrid product segments in stationary and motive areas. B) develop a cost optimized and simplified, yet robust DC/DC converter solution.

4.3.1 WP4 Fuel Cell controller

The first task was to make a KPI comparison of different controllers, suitable for fuel cell use.
A consolidation of controllers has been made. Five different solutions have been compared in the table below (Figure 16 16). The STW and an upgraded version of the currently used Fuel cell controller are the most promising when looking at connections, integration cost and unit price.

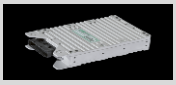
					
Technical Data					
Product:	(Bosch) FC Control Unit	(Bosch) FC Control Unit	STW	CompactRio	BPSE FC Controller
Type:	ME 17.9.6	EGC 4	ESX-3CM	Crio - 9035	NXP ARM7 LPC2383
Temp. Range:	-40°C to +95°C	-40°C to +85°C	-40°C to +85°C	-20 °C to 55 °C	0-60°C
Oper. Voltage:	8V ... 16V	16V ... 32V	9V ... 32V	9 ... 30 V	14-30V
Nominal Volt.:	13.5V	28V	-		24V
Inputs:	13 digital 17 analog	7 digital 25 analog 5 PWM	16 x Digital/analog inputs, 0 ... 40 V, 12-bit, 2 x Analog inputs, 0 ... 20 mA, 12 Bi	As required	**Seprate board:** 16 Digital inputs 22 Analog inputs 0-10 VDC
Outputs:	6 digital 13 PWM	7 digital 21 PWM	1 x Analog output 0 ... 20 mA or 5 ... 10V 10 x 2 A, high-side, with current measurement, short-circuit proof and diagnosable	As required	**Seprate board:** 28 Digital output 4 Analog output 0-10 VDC
Special Pins:	3 H-Bridges	H-Bridge Lambda sensor interface Knock sensor interface			
Communication:	CAN , Serial Com	4x CAN , LIN	4x CAN	User configurable- (CAN, Serial, etc)	2x Serial, CAN, LAN
Datalog	Yes	Yes		Yes	Yes
Lifetime considerations	10 years, 6.000 operating hours				
Connector	Bosch 2x56 pin		81 pin Automotive (tyco)		
Processor System					
Processor			32Bit - 150 MHz	1.33 GHz dual-core	16 Bit - 72Mhz
Flash			4 MByte external - 2 MByte external	4 GB	512 kB
SDRAM			4 MByte external - 80 kByte internal	1GB DDR2	4 MB
EEPROM			32kByte		64 kB
Software					
User software	Bosch Automotive standard	Bosch Automotive standard	Freely programmable "C"	NI software - LabVIEW	Freely programmable "C"
Environment					
Housing IP	IPx4k and IPx9K	IPx4k and IPx9K	IP67		IP00
Requirements					
Requirements			Vehicle, CE industri		
Price					
Price 1 - 10	€ 2.500,00	€ 2.800,00	€ 700,00	€ 2.882,00	€ 640,00
Price 10 - 50	€ 2.000,00	€ 2.000,00			

Figure 16 KPI comparison of possible FC controllers

A cost overview of the selected controls is listed below (Figure 17). The price does not include software development. It was not possible to get prices on Crio controller for 50 QTR; therefore, they are presented at the same cost as 1 QTR.

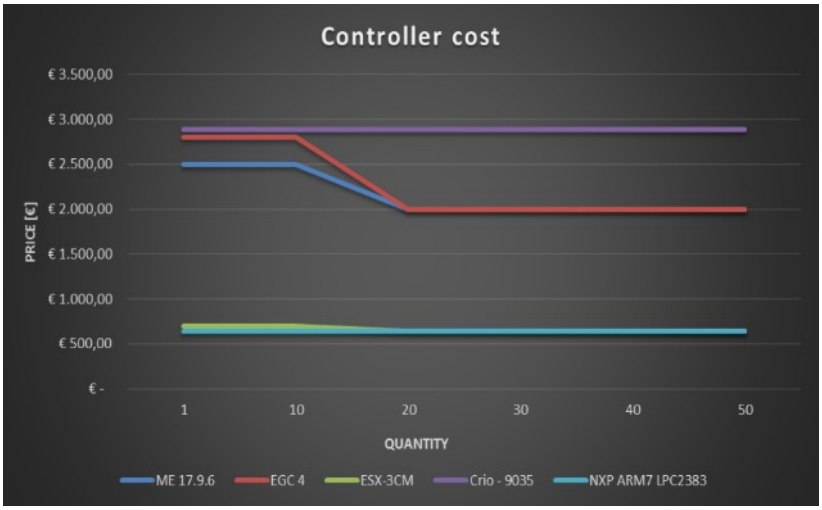


Figure 17 Controller cost comparison

It is seen that the true automotive controllers have a steep cost reduction curve when the volumes increase significantly. But the comparison also showed that the currently used controller is the most economical solution.

The study showed that controllers for automotive are hardly compatible with backup power installations. Infact, the requirements typical of the automotive industry like the heavy certification and the need for extra robustness, durability and reliability, makes the products extremely expensive.

Also, the fuel cell software should have been updated requiring massive extra work before a migration to another platform can happen.

For these reasons the efforts in the WP4 focused then on the second activity, to look at cost optimized and simplified robust DC/DC converter.

4.3.2 WP4 DCDC converter

The current solution is an ewirac topology patented by Ballard. It uses two transformers that can be reconfigured to operate in series or in parallel. There is an additional series inductor on the input port. The aim was to make the converter simpler and cheaper to manufacture while increasing the reliability of the system.

Figure 18 DCDC converter currently used in BPSE Stationary fuel cell applications

First a survey of applicable topologies was performed. There is a breadth of literature on wide gain DC/DC converters with the topologies including: full bridge isolated boost, full bridge isolated buck and LLC based topologies. Initially the search pointed at using a modified LLC converter with increased gain range (B/HB Switch, Dual-Bridge LLC, Buck-boost+LLC, Interleaved Boost+LLC, Three-level Bridge with VFX, Three-level Full Bridge, Three-level Bridge, Two Split Resonant Tank, Auxiliary Tx, Serial Connected; individual references available in DOI: 10.23919/IPEC.2018.8507899). These topologies have the potential of increasing the power density and lowering the hardware complexity. However, all of the potential candidates had very complex control structures making them very inflexible in adaptation and very hard in designing in a limited time span. The focus shifted to a fixed frequency LLC converter (DOI: 10.1109/TPEL.2017.2710162). Its principle is similar to ewirac as it changes operation from half-bridge to full bridge thus doubling the converter gain. The converter was very promising, as it is very simple in design and operation, but low output voltage proved problematic with achieving ZVS.

A very similar structure was a dual active bridge with DC blocking capacitors (DOI: 10.1109/TPEL.2017.2746518). Similarly, as in fixed frequency LLC converter, the converter could switch either of the input or the output bridges from half bridge to a full bridge operation. The resulting DC component is blocked by the series capacitors. The gain of the converter can be effectively halved or doubled extending the voltage range by 4:1.

AAU has made a simulation model of this topology to optimize its design with respect to the desired input and output voltage ranges and converter power. During the analysis, it turned out, that a dual active bridge topology, even without the range extension, could perform well with the fuel cell voltage range.

Due to very specific current-voltage characteristic of a fuel cell, it has been possible to design a dual active bridge converter that will be operating mostly in the soft-switching range. This opportunity was investigated for TM4.4.

A prototype dual active bridge converter was designed and prototyped in the lab. The converter was designed to operate with a 1020ACS fuel-cell stack.

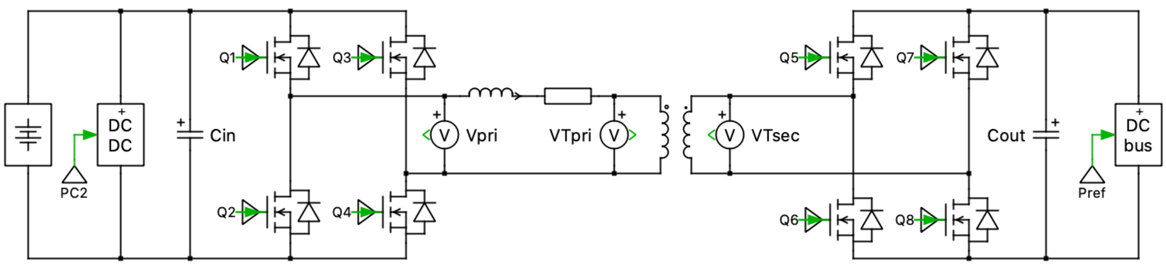


Figure 19 - Simulation model of the DAB converter.

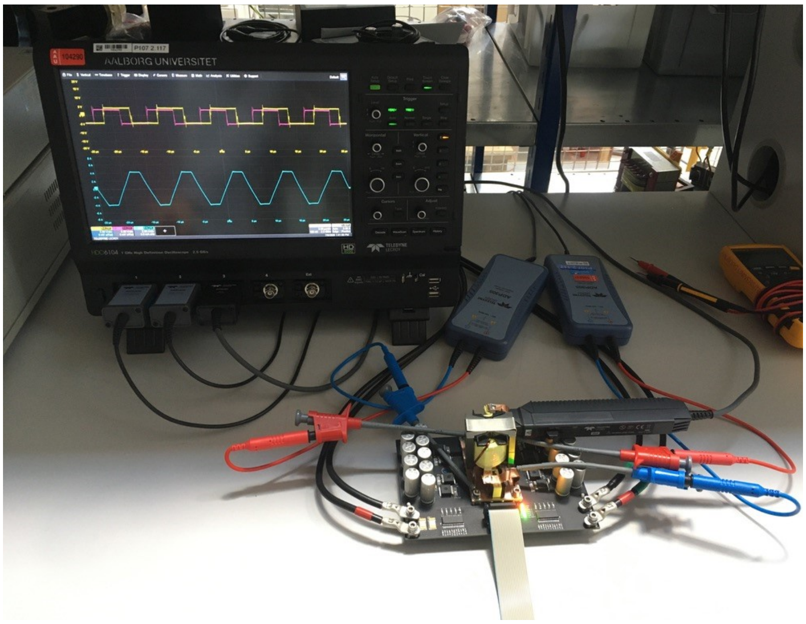


Figure 20 - DAB converter prototype

The prototype built uses a single-phase-shift control to control the flow of power. The converter is capable of bidirectional power transfer with a well defined soft-switching zone. A mathematical model of the converter was built to investigate the effects of converter component parameters on the soft-switching boundary.

The topology was optimized for a 52V output (nominal voltage of the controller reference). In order to fit the iv characteristic of the fuel-cell stack within the soft-switching region of the converter, a 1:1 transformer is used. That means that input voltage different than 52V will introduce additional reactive current circulating in the converter. Input voltage above 52V correspond to the low power region of the converter operation. This is where hard-switching can occur.

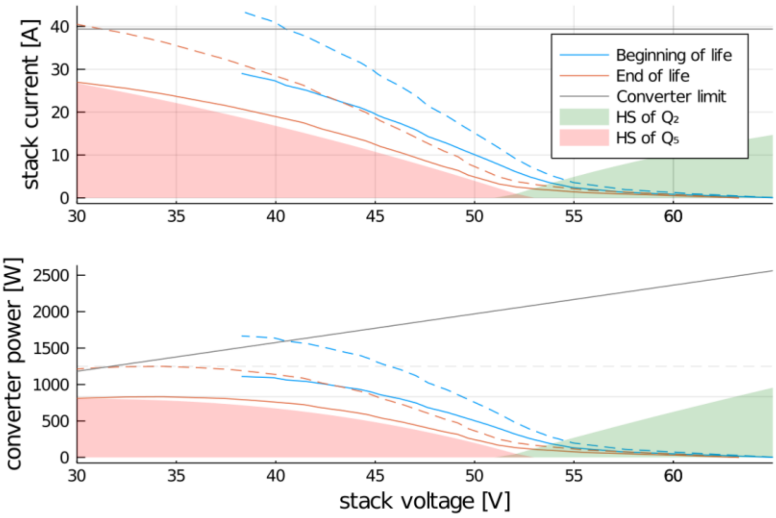


Figure 21. Hard switching zones of the proposed power converter with superimposed current-voltage characteristics of the 1020ACS fuel-cell stack.

The dual active bridge converter can be controlled using three basic modulation strategies:

- Simple phase shift (SPS) control, where both full bridges operate with 50% duty cycle and the control is performed by adjusting the phase shift between the two bridges.
- Extended phase shift (EPS) control introduces additional phase shift either in the input or the output bridge. This introduces one degree of freedom in the control system allowing for optimization.
- Triple phase shift (TPS) introduces phase shifts within both input and output bridges. Two degrees of freedom allow for even more extensive optimization.

All modulation methods must preserve the zero volt-second balance to prevent the saturation of the magnetics.

Degrees of freedom in the control system allow for optimization, but at the same time introduce complexity. Many methods were proposed for controlling DAB converters using TPS. Experiences from TM4.4 show that the biggest problem lays within high power region, when the voltage of the fuel cell drops down to ~30V; and at very low power, when fuel-cell voltage is above the DC grid voltage, when converter enters hard-switching area for the output bridge.

Regarding the DCDC converter´s controller, after careful analysis a global minimum backflow power control (GMBPC) strategy was chosen for controlling the DAB converter. This control method uses only two external inputs: input and output voltage. This allows the removal of the current sensor dedicated for each of the phases in parallel-connected converters. In the previous design the sensor was a high-side DC current shunt that introduces additional power losses. We suggest using a low-bandwidth low-accuracy sensor instead.

The GMBPC control strategy aims at minimizing the backflow power, thus minimizing the reactive power in the converter. It can also preserve soft-switching in wide-operating area.

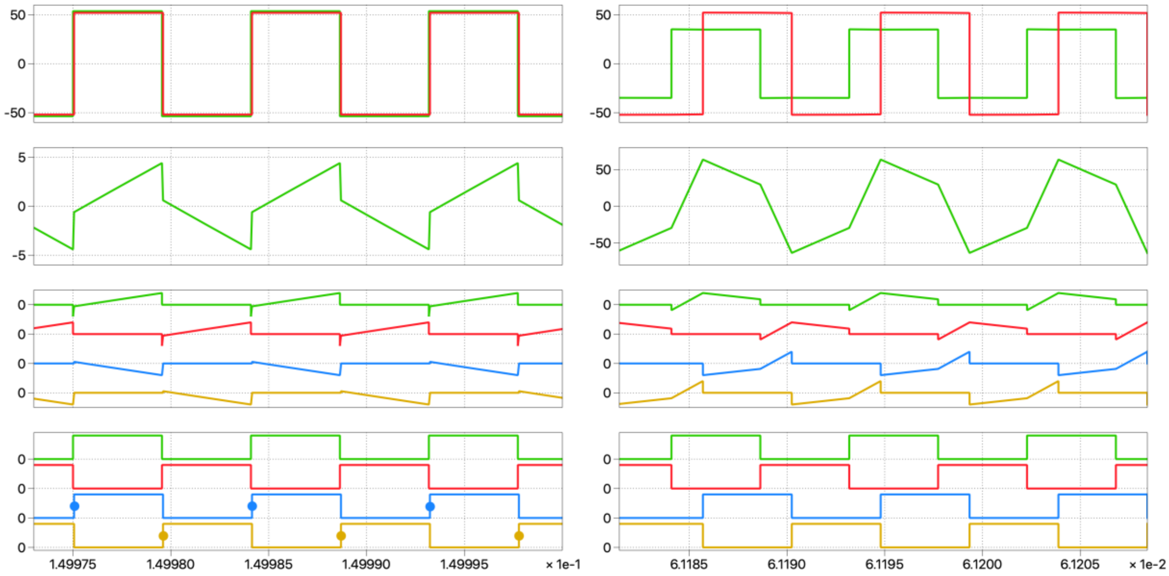


Figure 22 - SPS modulation applied to the converter at low (100W, left) and high power (1250W, right). Hard switching marked with dots. From top: [Vin Vout]; iL; [iQ1 iQ3 iQ5 iQ7]; [vgsQ1 vgsQ7 vgsQ7 vgsQ7]

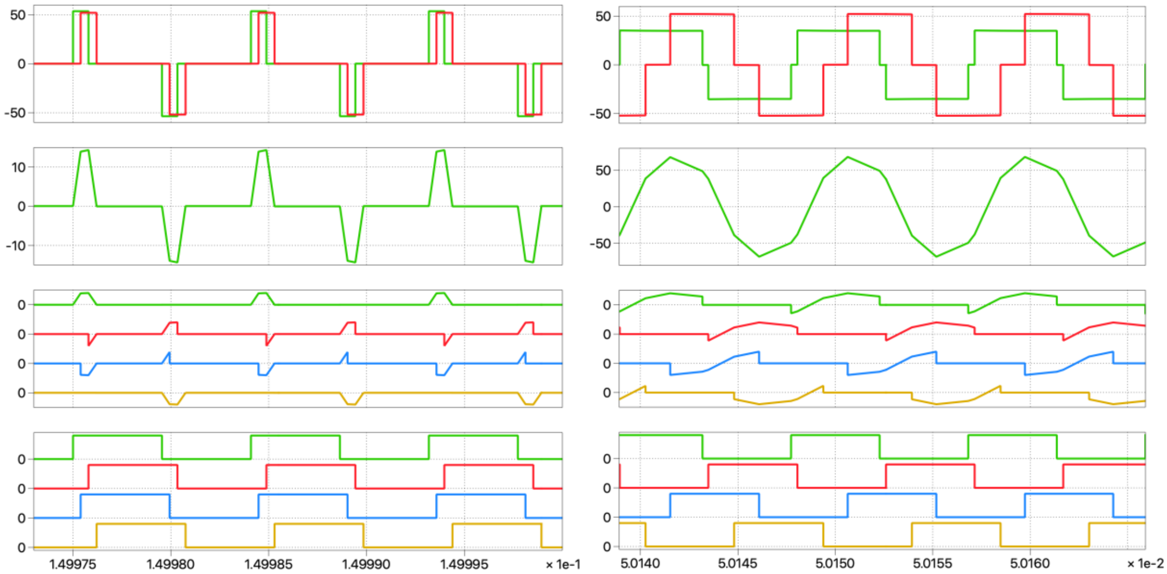


Figure 23 - GMBPC modulation applied to the converter at low (100W, left) and high power (1250W, right). All switches experience ZVS/SCS. From top: [Vin Vout]; iL; [iQ1 iQ3 iQ5 iQ7]; [vgsQ1 vgsQ7 vgsQ7 vgsQ7]

As can be seen the GMBPS can preserve soft-switching in both light and hard load conditions. It also provides lower $i_{L(RMS)}$ current at very low current levels increasing.

For the Power transformer a planar style design was chosen for the design. This kind of design uses a PCB for internal winding construction. It does not require coil formers so the window utilization is better than in traditionally wound transformers. Prototyping cost is very high as is requires a custom PCB stack-up but it promises a minimal assembly cost as it is limited to clipping the core on the PCB. For prototyping we chose to use a laser cut 0.3mm copper sheet with 75µm laser cut Kapton sheet. This allowed us to experiment with stack-up. Two ferrite 95 E-cores from a Fair-Rite 7895400421 EI set were used.

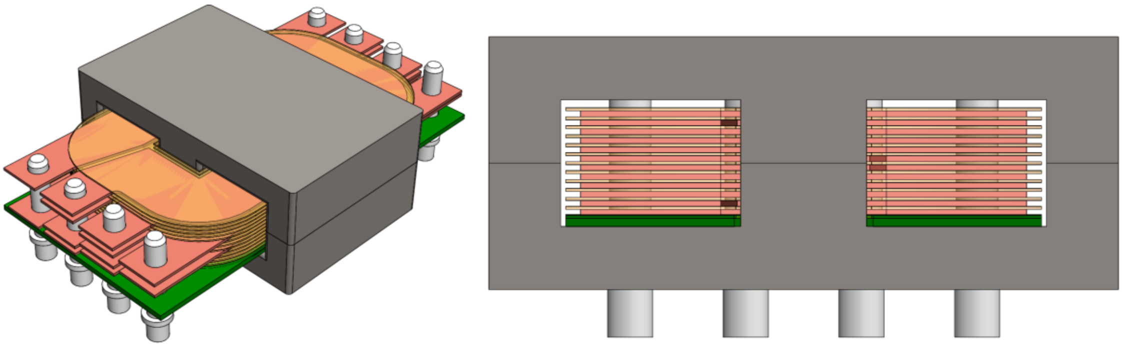


Figure 24 - Planar transformer CAD model with its cross section.

The transformer consists of three primary and three secondary windings. The winding stack-up will have an effect on the parasitic properties of the transformer (inter-winding and primary-to-secondary capacitances). Two interleaving patterns were used:

P11-S11-P21-S21-P31-S31-S32-P32-S22-P22-S12-P12 (interleaving 1)

P11-S11-S12-P21-P22-S21-S22-P31-P32-S31-S32-P12 (interleaving 2)

With naming scheme used: P/S (primary/secondary), 1/2/3 (position in series connection), 1/2 (position in parallel connection). Layers were insulated with each other by two 75µm Kapton sheets. In total, the stack-up height is 5.55mm with window height of 6.35mm. The remaining window height is used for a PCB that helps with pins that join the individual layers and for manufacturing tolerance of the stack-up.

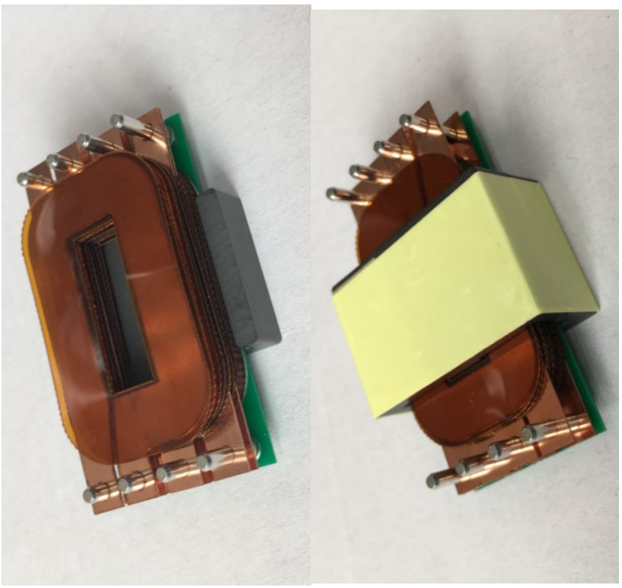


Figure 25 - Planar transformer prototype.

With having the windings laser cut out of copper sheets we could experiment with the individual windings. We tested an idea to lower the AC resistance of the layers by introducing cuts along the winding layers that should, in theory, equalize the current density along the width of the copper path.

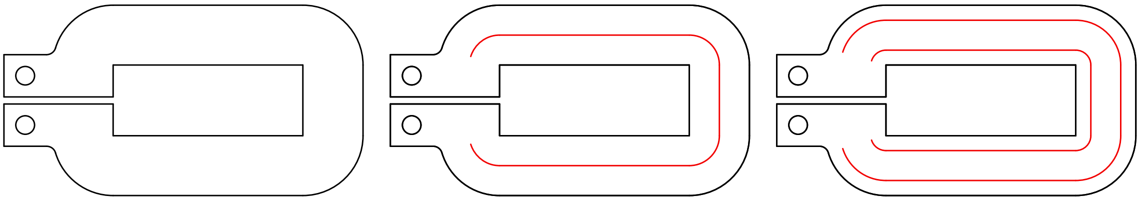


Figure 26 - Transformer winding with no cuts, one cut and two cuts.

Due to the skin effect the current will tend to move to the edges of the conductors. In high frequency applications this is counteracted by using multiple individual paralleled wire strains, Litz wire or foil windings. In individual layers of a foil windings, the current will try to concentrate close to the edges of the copper ribbon.

The current in a winding tends to also concentrate close to fringing magnetic fields. In gapped inductors, this can be seen close to the gap, therefore we want to move the windings away from it. We propose to use the same mechanism to compensate the tendency of the current to move to the edges of the foil. By introducing cuts and offsetting them, the current density should concentrate closer to the gap of adjacent track. This should equalize the current density in the layers. The stack-up should include layers with alternating layers with one and two cuts.

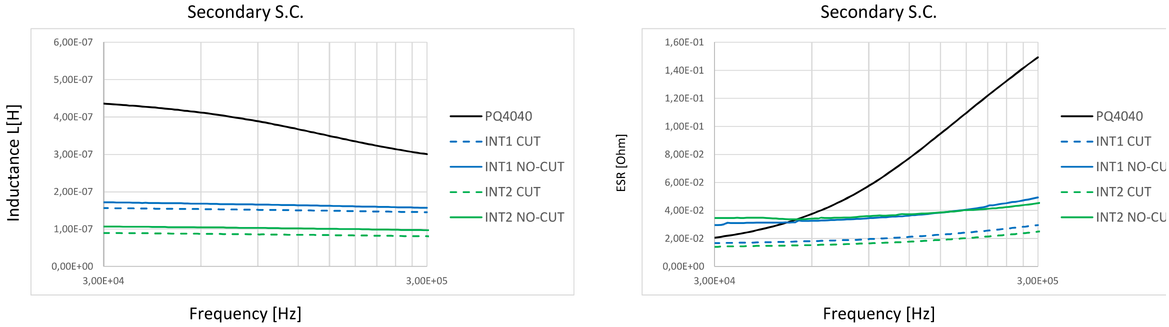


Figure 27 - Measured inductance and resistance of the planar transformer. Secondary windings shorted.

Measurements show that the AC resistance (ESR at the switching frequency of the converter) is halved when cuts in windings are used.

4.4 WP 5 evolution

The demonstration site for the hybrid installation was initially identified in the area of Aarhus, then changed into Aalborg because Aarhus has been elected “European capital of culture 2017” and it was not possible to get permits for building a site there.

The optimal hybrid solution for has been then designed using the design-tool prototype developed in WP 3. The shelter solution at the ACCESS site in Aalborg will be configured like shown in the Figure 28.

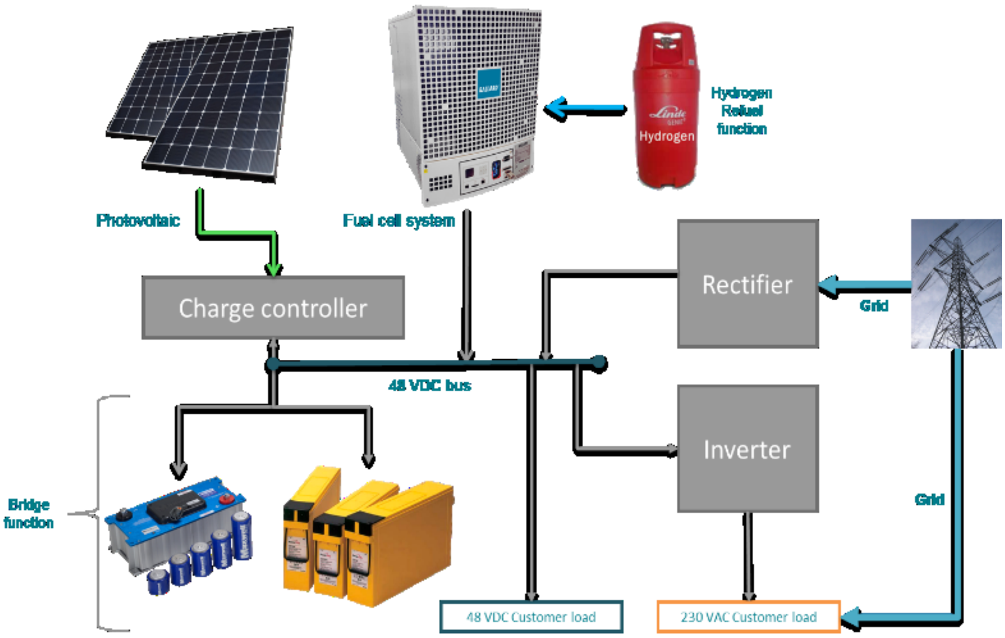


Figure 28 - Hybrid system overview

The primary source of energy comes from the grid, and the Photovoltaic should provide as much as possible to the 48 VDC bus. The fuel cell system was intended be the “second” back up unit.

Then the original plan to install the hybrid shelter in a Stofa Demo site in the autumn of 2017 was postponed because of Stofa´s plans to build a larger site for the test in Nørresundby. The installation should have taken place in Q1 2018. Due to lack of approval of the building permit, it has not been possible for Stofa to complete the construction of the shelter in Nørresundby. New location were investigated, in the Aarhus area, with a similar solution but a smaller roof area for solar cells.

The location for the Hybrid shelter was finally found in Viby near Aarhus.

The installation includes a hybrid electric FC system with 4.5 kW fuel cell power, 9.6 kWh battery capacity, and 2.4 kW solar panels, for a site load of 7 kW.

The site initially selected had a load of 4 kW and the solar cell power of 6 kW. The changes had a major impact on the solution, which is sub-optimal, how illustrated in the TCO report which also shows that the solar cell installation was financially an unprofitable decision. The TCO also investigated the possibility of installing a hybrid PV-panels, fuel cell and batteries system on an off-grid site.

Figure 29 - Hybrid system installation

4.5 WP6 evolution

- **WP6 Dissemination (CEM)** comprises the dissemination plan and aims at disseminating the projects aims, progress, findings and results to relevant stakeholders through selected means of dissemination.

The communication focused on spreading knowledge about the projects existence, progress, findings and results to relevant stakeholders within the field and to the broader public for raising awareness about the maturity of renewable solutions and hydrogen technologies.

The first press release about the project was published in the beginning of January 2017 (in both Danish and English) It has been shared on Hydrogen Valleys website and Social Media channels.

A Position Paper has been developed. This will be used as a platform for communication going forward in the project.

Logo for the project has been designed.

Figure 30 - Logo for the CrossCut project

In 2018, the Crosscut project was presented at the annual Hydrogen and Fuel Cell Day

Figure 31 – Hydrogen and Fuel Cell day

Hydrogen valley published an article about the TCO software that will be made in the project. In connection with the hybrid shelter solution. The article was published on the Hydrogen val-ley website and on the Energy Supply news page.

Hydrogen Valley has given several company presentations where the Crosscut project has been presented All the material has been shared on Hydrogen Valleys SoMe channels

5. Project results

The original objectives of the project have been substantially obtained.

Regarding the development of tools for TCO and data collection, the objectives have been largely obtained. The realization of a new generation DCDC and related FAT tester is also a success in the project. The hybrid shelter installation with Fuel Cells, batteries and solar panels has been a partial success, because apart from the CO2 emissions reduction, and the ensured backup time, the specific installation revealed itself suboptimal under the economic perspective. The adoption of an automotive fuel cell controller for backup power system also didn´t result applicable.

The results of the project are good from the tools perspective. In particular, the TCO tool and the big-data analysis tools have a major commercial relevance.

6. Utilisation of project results

Communications network connectivity and stability have never been more important, and it is getting more crucial to keep the network running. The COVID-19 situation in 2020 really emphasized how dependent our lives and businesses have become on remote and reliable data communication. Within weeks, the survival of millions of companies worldwide was depending on functional, secure data connections in order for employees to be able to work from home and for businesses to live through the Corona lockdown crisis. It was also highly important for people to communicate with friends and family online in a time of social distancing, restrictions and curfews. Fuel cells plays a vital role in ensuring this reliable power supply for communications networks.

The commercial results from CrossCut is largely related to Ballard's commercialization of backup power fuel cell systems. The commercial results of the project can be divided into two different overall results: 1) Improvements on our Fuel Cell Backup Power Systems 2) A Hybrid PV and Fuel cell back up power system.

1) Fuel cell backup power systems

In terms of the general telecom market Ballard is currently focusing on the Scandinavian market. The current market situation here is that Ballard has sold and delivered 550 units as of 2020. Ballard enjoys a leading position when it comes to fuel cell backup sites with 99% of the fuel cell back up power systems in Scandinavia being Ballard fuel cell systems as indicated in the figure 1 below. But as one can also see there is still a lot of potential in the market that Ballard can pursue.

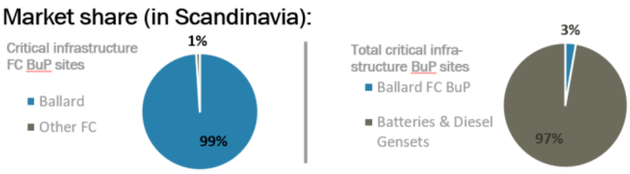


Figure 32 FC BuP Market share in Scandinavia

The market drivers for fuel cell backup power can be divided in to and increasing dependency on critical Infrastructure for communications, Network Hardening of Critical Infrastructure, Legislative requirements and Environmental aspects.

Increasing Dependency on Critical Infrastructure for communications: With the world becoming more and more the digital the increasing dependency on the critical infrastructure for communications worldwide is a critical factor: "The world has more to lose than ever before from massive failure of critical infrastructure." (World Economic Forum: "Global Risks", 2015, 10th Edition)

Network Hardening of Critical Infrastructure: Critical Communication Infrastructure is attracting more and more attention from a national perspective as public safety, healthcare and critical transactions are depending on the reliability of such infrastructure.

Legislative requirements: Progressive legislation on operational reliability for e-communication services in the Scandinavian countries; Sweden and Norway as the front runners with Denmark and Finland catching up on their standards. Scandinavian countries are increasing backup time requirements and new legislations are being imposed. In Norway there is requirements of minimum 72 hours of backup power, in Sweden the requirements is of 6 - 8 hours and in Denmark the requirements is 6 – 24+ hours. In Denmark the ambitious requirements has been set by the telecom providers and not legislation, but they are non the less still requiring long back power.

Environmental aspects: Recent trends in the transportation sector regarding out phasing diesel also affects the Critical infrastructure providers as operators don’t see diesel generators as a future proof solution. With spillage incidents, diesel solutions are raising concerns with operators. Also the low reliability of diesel generators makes such solution a less attractive alternative today. Issues regarding re-cycling of batteries with hazardous chemicals are not yet affecting operators’ decisions.

2) Hybrid PV and Fuel cell back up power system.

For the hybrid PV and Fuel cell backup power system the market conditions is in general the same as for fuel cell backup power systems in general. But we have received interest from other customers in the hybrid solution.

Future plans:

The current approach of Ballard is to focus on the Scandinavian markets where the requirements for Critical Infrastructure are very favourable for fuel cell backup power solution and to prepare plan for long term future market growth in other countries with similar market drivers.

7. Project conclusion and perspective

The original objectives of the project have been substantially obtained. The TCO and data collection objective has been reached and a new generation of DCDC has been realized and have a major commercial relevance. But the hybrid shelter installation with Fuel Cells, batteries and solar panels was only a partial success as the specific installation revealed itself suboptimal under the economic perspective. But the solution has still received interest from customers that find the reduction in CO2 emissions highly valuable.

The results and the work in crosscut has been beneficial to other back up projects such as SPGC and RUBY where we in the latter are working with predictive maintenance to reduce the TCO of our systems.

The next step for the technology is to penetrate the Scandinavian critical infrastructure market. This will result in a scale up in the production of back up power systems at Ballard in Hobro.