Final report for EUDP Journal number: 64010-0455

EUDP 10-II, Emerging DMFC Power

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Resume

English

In the project a 1600W nominal UPS system with a DMFC runtime extension has been designed and constructed.

The systems have gone trough a CE certification process and have been integrated into five Point Of Presence stations.

The systems have successfully been field tested for a year in an IT application without requiring components to be replaced.

The market for DMFC based solutions have been investigated and it has been identified that there is an additional potential market for long term UPS backup as well as APU applications.

Dansk

I projektet er der der designet og konstrueret et nominelt 1600W UPS system med en DMFC baseret runtime ekstension.

Systemet har været igennem en CE certificerings process og er blevet integreret i fem ”Point Of Presence” stationer.

Systemerne er succesfuldt blevet testet i et år i en IT applikation i felten uden, at det har været nødvendigt, at skifte komponenter.

Markedet for DMFC baserede løsninger er blevet undersøgt, og det er blevet konstateret, at der er et nyt potentielt marked for langtids UPS backup samt APU applikationer.

Introduction

The objective for the 30[1] month project were to develop a 1kW DMFC unit and demonstrate it in a longterm application in an end user environment.

The project consortium consisted of 3 project partners:

- IRD, project coordinator and responsible for the development of the DMFC unit.
- Dansk Gasteknisk Center, CE-certification and neutral testing of the APU unit.
- Tre-For, host of the five field test units.

As the design targets for cost, lifetime and efficiency the Danish national 2014 DMFC road-map targets were to be used, at the time: Cost (9000 €/kW), efficiency (25% el) and stack lifetime (5000 hours)

The outcome of the demonstration project were a strengthening of the knowledge concerning the future R&D challenges and market demands that needed to be meet in order to commercialize the DMFC technology.

The project were divided into the following main phases:

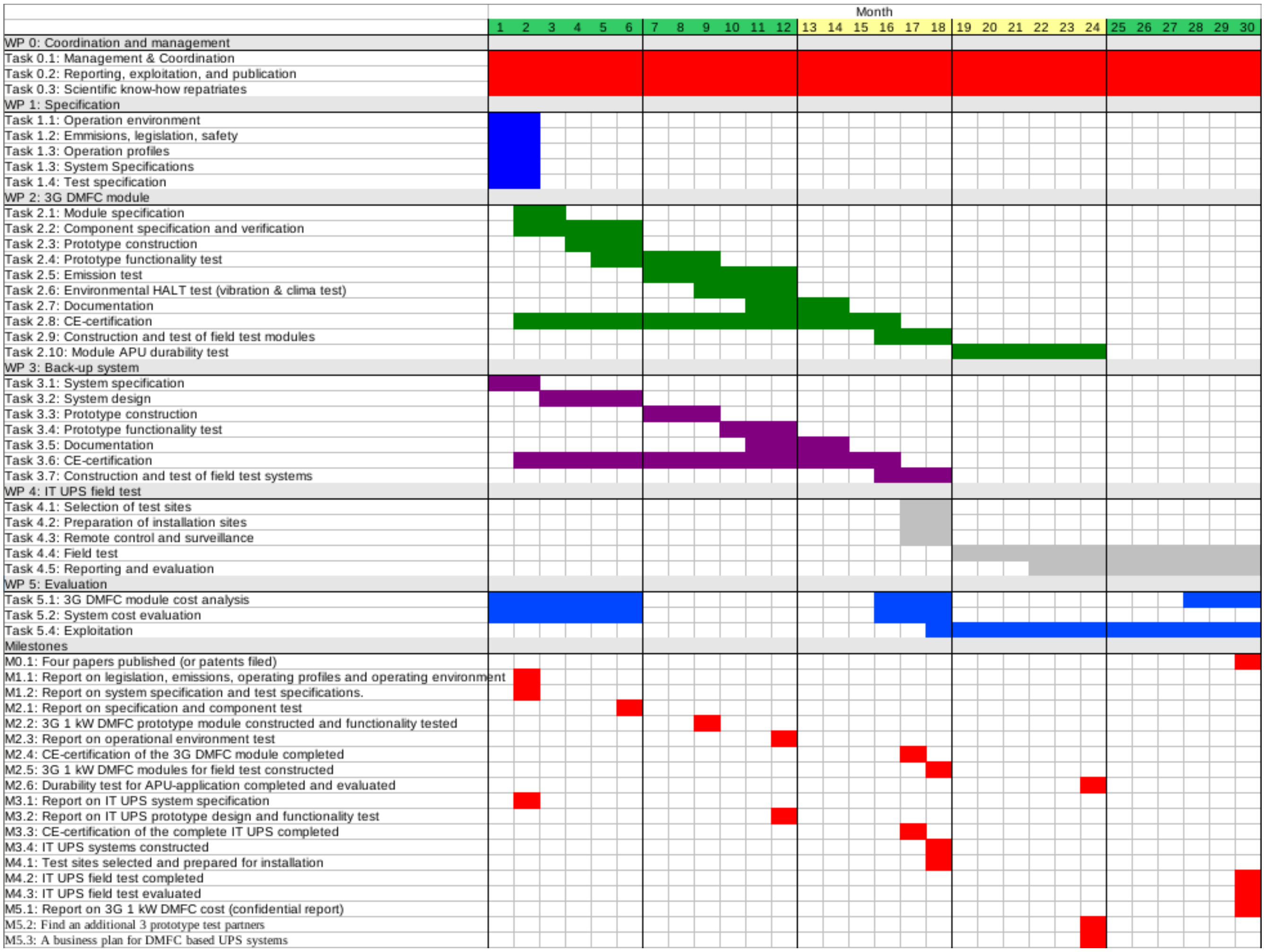
- WP 0: Coordination and management.
- WP 1: Specification (Environmental and operational).
- WP 2: 3G DMFC module.
- WP 3: Back-up system.
- WP 4: IT UPS field test.
- WP5: Evaluation.

In order to increase the value of the knowledge gathered it was additionally agreed with EUDP that a further unfunded 3 test environments were to be found outside the original project partners.

1 Originally only 24 months but the field test period was extended with an additional 6 months

Project gantt diagram

The project have been following planned course as depicted in the gantt char below.



All milestones was completed in the course of the project.

WP 0: Coordination and management

Objectives

The objective for WP0 was the following:

- Financial management
- Communication with EUDP
- Project management
- Compilation of periodic reports
- Exploitation of the results obtained
- Dissemination of the obtained results

Management and coordination

As part of general management and coordination a steering committee with members from all project partners was founded.
The committee meet every 3 months to discuss the progress in the project and identify problems that needed special attention.
Apart from the steering committee meetings a number of topic specific meetings were held.
These meeting only included the relevant personnel from the involved partners.

Dissemination

As the project was nearing its completion and over half of the field test had been completed an public meeting there were held on the 28. of February 2013 about the project at Tre-For in Kolding.

The meeting included presentations about the results achieved in the project, Tre-For's experiences as an end user and an introduction to the certification process.
The attending guests among others included potential end users from other Internet provider companies and a few guests related to other types of fuel cell technology.
EUDP was also invited to hold a presentation about there mission and the research project application process in general.
Apart from the meeting the project have been mentioned in 3 non scientific publications reaching a broad audience.

Exploitation

In order to fully exploit the potential of the project the following patent has been applied for:

`WO 2012/103537 A2`

`Title: Method and system for stable direct methanol fuel cell operation at varying loads and sub-zero temperatures`

`By: Andresen, Visti; Bonde, Jacob, Lindner; Lundsgaard, Jørgen, S.; Lundstrøm, Mads; Odgaard, Madeleine`

WP 1: Specification (Environmental and operational)

Objectives

The main objective of WP1 package is to prepare WP2 and WP3. Ensuring that the systems will be built to fit the specifications required for the proposed UPS application and that the components will be tested and developed to fit the correct specification. The main results of the tasks in this WP are summarized below.

Operation Environment

So called “Point Of Presence” stations hereafter called POP stations were selected as the IT application in which to test the DMFC units.

The POP stations owned by Tre-For were already supplying Internet and television signals to existing customers, it was therefor very important that the project didn't interfere with the normal operation of the POP stations.

The POP stations contains a lot of expensive and sensitive IT equipment. As a direct result it was not allowed to send the exhaust into the room as it contains moisture.

Additionally some of the Cisco equipment required the air to be free from particles down to pollen sized objects.
This requirement had resulted in the POP stations to be sealed.

Due to the fact that the POP stations were already build and installed we were not allowed to use external cooling components as this would require new building permits to be applied for and the aesthetic change might also upset local residents.

Illustration 1: POP station in Kolding prior to installing vandal proofing of the intake / exhaust

As heat build up inside the POP stations were already an issue we not allowed to use the internal air for cooling either.

With regard to the physical size of the unit we were allowed to take up one 19 inch cabinet including batteries and methanol storage.

Operational Power requirement

Tre-For required a uptime of two hours from the UPS, as this would give them sufficient time to send a technician to reestablish a source of mains power and air conditioning for the POP station.

The power requirements of the POP stations varies depending to the amount of equipment installed and the utilization of the station.
Two power ranges were identified 800W and 1600W.
With a jump in power requirement if an additional fiber optical switch was needed to service the users.

POP station	No. of switches	Switch utilization	Power usage[2]	Power specification
FRE-01-05	1	92.2%	741W	800W
FRE-05-03	2	59.2%	1210W	1600W
KLD-06-01	1	36.7%	296W	800W
MID-01-07	1	46.4%	396W	800W
VEJ-01-05	1	55.5%	518W	800W

The power usage as a function of time of day was also examined and found to be relative constant.

The following 24h power usage data was obtained for the 5 POP stations:

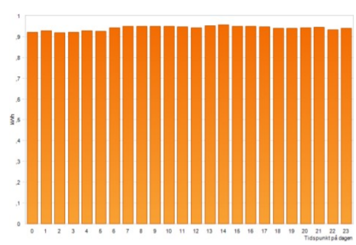


Illustration 2: Power as function of time of day, FRE-01-05

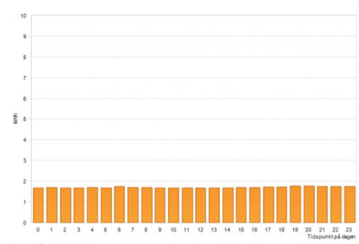


Illustration 3: Power as function of time of day, FRE-05-03

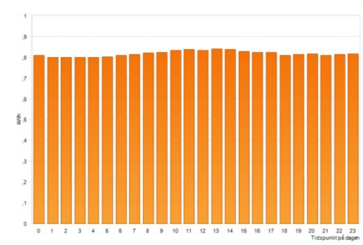


Illustration 4: Power as function of time of day, KLD-06-01

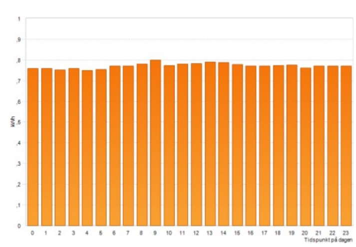


Illustration 5: Power as function of time of day, MID-01-07

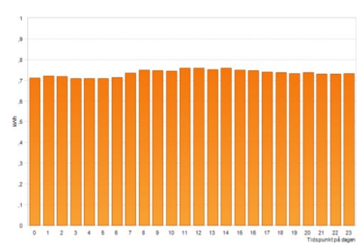


Illustration 6: Power as function of time of day, VEJ-01-05

2 Without air conditioning

WP 2: 3G DMFC module

Objectives

The objective of WP2 is to construct and certify the 3G 1kW DMFC module according to the specifications made in WP1.
The main emphasis is to design a module with the fast and predictable start-up time that is required for an UPS system. This will require that the current DC-DC step up electronics of the 2G module has to be optimized. Initially BoP components/materials will be identified and tested in order to ensure that the lifetime and the emissions from the system components are according to specifications made in WP1. One of the main tasks will be optimization of the fuel circuit, where the experience from IRD (system reliability and materials) and DGC (safety and materials) will ensure that the optimal materials are chosen. The identified materials will be subjected to extensive test, to verify that they comply with the specifications from WP1. A revised BoP system will be constructed around the verified components leading to the 3G prototype. The prototype will alter be subjected to test according to the test specifications drafted in WP1. Finally CE-certified units for field test will be constructed. In the following an summary the results of WP2 will be given.

DMFC 3G module Specification and design

The project was specifically not intended to involve the development of a new stack as this was already covered by the EUDP-2009 projects:

- TailorPEM Part-I journal number: 64009-0016
- PEM Low Cost Endplates journal number: 64009-0217

Due to the power demand of the demonstration UPS application the design were based on the 800W stack[3].

Due to the relative low altitude of Danish UPS installations the operational sealing was set to 500 meters above sea level.

Illustration 7: DMFC 3G module

As the DMFC unit was supposed to be capable of being used both for APU and UPS applications it was decided to construct the DMFC as a self contained unit that only required a external battery and a source of methanol.

As the methanol source the commercially available methanol cartridges were chosen as they are readily available, safe and easy to handle and has a sufficiently good purity of methanol for fuel cell applications.

3 The smaller and cheaper 500W stack has a similar connector layout and the Balance Of Plant components were selected in such a way that a 500W version could be constructed with relative minor changes.

Certification

General certification

During the certification phase DGC assisted in the HAZOP analysis of the module.
They also used there expertise with regard to rules and regulations and assisted IRD in the certification process.
Safety pressure tests were also conducted by DGC.

EMC

As part of the CE certification process Electro Magnetic Compatibility had to be verified

The EMC test was done by Delta at there facilities in Them.

After the modifications had been completed the DMFC was capable of passing the EMC test:

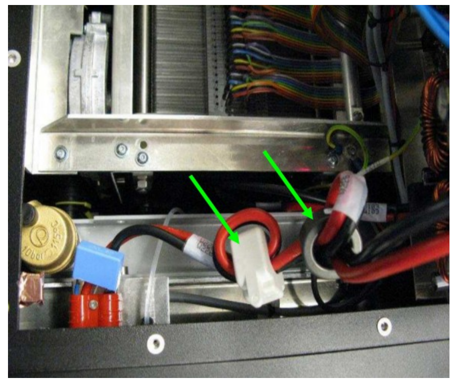


Illustration 8: Ferrites added in order to pass the EMC test

Tests	Test methods	Results
Immunity to electrostatic discharges	EN/(IEC) 61000-4-2:1995+A1+A2	Passed
Immunity to radio frequency electromagnetic fields	EN/(IEC) 61000-4-3:2006	Passed
Immunity to fast transients	EN/(IEC) 61000-4-4:2004	Passed
Immunity to surge transients	EN/(IEC) 61000-4-5:2006	Passed
Immunity to conducted radio frequency disturbances	EN/(IEC) 61000-4-6:2007	Passed
Immunity to power frequency magnetic field	EN/(IEC) 61000-4-8:1993+A1	Passed
Immunity to AC mains voltage dips and interruptions	EN/(IEC) 61000-4-11:2004	Not relevant
Measurement of radio frequency voltage on mains	CISPR 16-2-1:2008	Passed
Measurement of radio frequency electromagnetic field	CISPR 16-2-3:2006	Passed
Measurement of mains harmonic currents	EN/(IEC) 61000-3-2:2006	Not relevant
Measurement of mains voltage variations and flicker	EN/(IEC) 61000-3-3:1995+A1+A2	Not relevant

HALT

The unit was additionally subjected to a HALT test using Deltas facilities in Hørsholm.
The test involved a combination of 6-axis (approximated) vibrations 0-70 Grms and temperature variations -30°C to 70°C.

The unit performed satisfactorily during the test. Some weak spots were however identified it was for instance necessary to upgrade the mounts for the air filter.

Some operational limits were also identified.
The unit shouldn't be operated at or above 40 Grms as

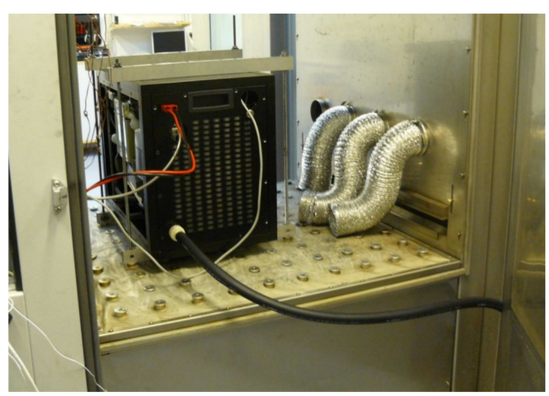


Illustration 9: DMFC HALT test

the stack showed signs of the seals leaking.

Durability and functionality test

One of the tasks assigned to DGC was the impartial test of the function and durability of the DMFC as an APU generator and as a module for the DMFC UPS system. They therefor received the first generator prototype for testing.

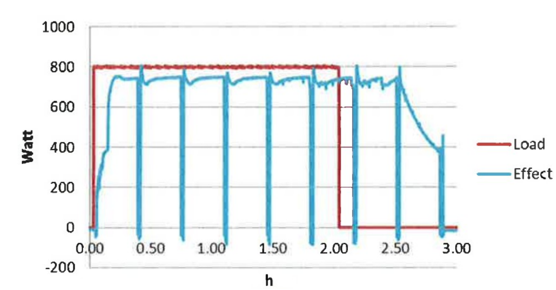


Illustration 10: Test profile

As a test it was decided to run the generator for 2 hours continually then removing the load. The 2 hours being the nominal minimum up time of UPS system, a example of this test profile can be seen in illustration 10.

The test was repeated 30 times, in Denmark 30 power outages is currently considered a lot even over a 30 year period as we currently enjoy a very reliable power grid. This may however change when a more substantial part of the energy is provided by renewable sources.
DGC measured the average electrical effect generated by the fuel cell. The result of the measurements can be seen in illustration 11.
The power measured was the module power delivered to the battery bank, the stack produces roughly 110W more than this.
This power is used for powering the BoP components and as losses in the battery charger and internal 24V DC-DC power supply.

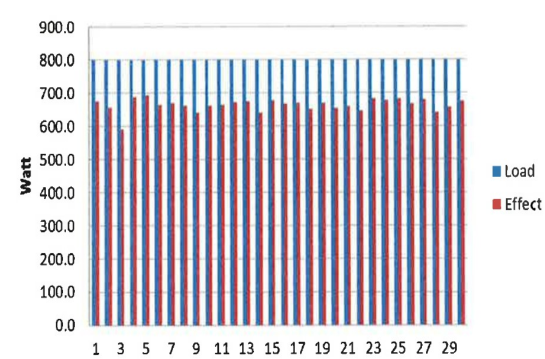


Illustration 11: Average effect over 30 tests

The power output remained more or less constant during the test.
The average power output was measured to be 664W including refresh cycles.

It should be noted that while this accelerated test should represent more runtime than would be expected during a 10 years of UPS application use it doesn't include the large number of low power maintenance cycles it would perform in order to replenish its water tank, kill off biological growths and verify that it can still run.

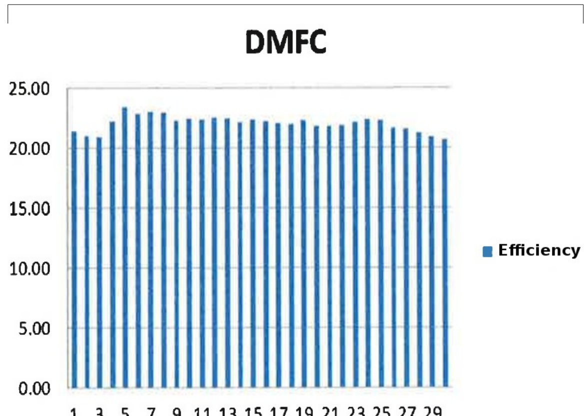


Illustration 12: Efficiency over 30 tests

Illustration 12 contains the efficiency measurements taken by DGC.
The measurements were done by measuring the methanol consumed using a weight and comparing it with the electrical energy produced.
The average electrical efficiency was measured by DGC to be 22% on the UPS system during simulated power failures, including the startup and operation at 100% power output only. Operation at shorter intervals will give lower efficiency due to the fuel used during startup, whereas operation at for

instance 50% power output will give significantly higher efficiency, this has however not been validated by DGC.

The project target for efficiency was 25% electrical on a DMFC module basis, which can be achieved by operating the module at a lower power point where the stack and BOP is more efficient.

DGC concluded that there had been no significant reduction in performance or efficiency during the test of the generator.

Apart from the performance tests DGC also performed durability/safety testing with regard to pressure.

The generator was split into 3 sections:

1. Heat exchanger and stack (air side)
2. Cooling circuit
3. Water tank, mix tank, stack (fuel side)

Each section was individually tested, the test consisted of:

- A leak test
- An overpressure/strength test (1.5 times normal operational pressure)
- Another leak test

After the first safety test the generator was subjected to the durability test and a test where the exhausts and intakes were blocked
During the tests the methanol concentration was measured along with CO levels[4]

After the durability tests an additional pressure test were performed to verify that the use and abuse hadn't weakened the generator seals.

Methanol, CO_2 and CO emissions during normal operation were also measured.

Methanol emissions were not unsurprisingly found to be highest during refresh cycles where the stack current is reduced to zero and the methanol has an increased probability for diffusing from the fuel side to the air side.

And while no CO could be detected in the exhaust the generator naturally produces significant amounts of CO_2 when operating, it is therefor essential that the generator is only operated in a well ventilated areas or that the exhaust be vented to the outside.

DGC also measured the external temperatures on the generator, and found those to be of no safety concern.

4 CO levels were below the detection level of 1 ppm

DMFC test internally at IRD

During the project a significant effort was devoted to test, component specification and the specification of Methanol. Since component and fuel impurities are one of the factors that may limit lifetime of the module.

A test specification protocol for methanol was developed and several new potential methanol suppliers were identified. Similar tests where performed on exhausts to determine the efficiency and service interval of the system filters.

In addition test protocols for component purity where developed to ensure that the system durability was sufficient.

In order to prove the fulfillment of the durability target of 5000 hours in a UPS module several approaches can be taken. The 5 systems in the field test where in operation for 39600 hours during the project, while running for 128 hours.
Thus each stack has been in operation for 7920 hours and has been running between 15 and 44 hours this can be considered as fulfillment of the 5000 hours stack lifetime.
Concurrently to this project an accelerated stress test was performed on a similar DMFC module in the DuraPEM II PSO project where 3600 hours of operation was proven during a period of 10 months, extrapolation of the data from this test and from single cell test all indicate that even 5000 hours of stack life is possible under full load.

WP 3: Back-up system

Objectives

The objective of WP 3 is to develop a backup system for the DMFC module that ensures fast and reliable backup power at all times.

The UPS system will be based on the DMFC module, which is concurrently developed in WP 2. The UPS system will be able to deliver the required power for the UPS system used by TRE-FOR.

The main emphasis will be reliability remote health monitoring and fast start-up. In the following and overview of the main results in WP3 is given.

Specification and design

In order for Tre-For to have enough time to respond to a power outage the UPS systems needed to have a uptime of at least 2 hours.

Tre-For also had determined that there power were a usage of 800W or 1600W[5] depending on the number of fiber switches installed in the POP station.

Initially it was considered to design two types one for each power level.
This was however eventually rejected as the savings in component cost didn't justify the inflexibility of having to replace the units if an additional fiber switch was installed.

The UPS system was designed around off the shelf UPS components and batteries with the DMFC functioning as a runtime extension for the UPS batteries.

Off the shelf components had the clear advantage of being mass produced and already having proven them self as safe and reliable.

An APC UPS[6] was chosen as the base for the system.
Apart from the build in battery an additional 3[7] battery packs[8] were installed in the system.
The batteries also serve as a power source for the DMFC during its startup when grid power was failed.

In order to meet the requirements for emissions into the POP station the standalone DMFC generator had to be mounted inside a manifold allowing it to circulate air from the outside without allowing pollen and other dust particles to contaminate the interior of the POP station.

All components were installed inside a standard 19” rack with enough room left for a methanol cartridge.

The DMFC is connected to the serial port of the UPS, and software

Illustration 13: UPS and battery packs

Illustration 14: DMFC in manifold

5 Depending on utilization the power used may actually be lower.

inside the DMFC had been written to communicate with the UPS.
This allows the DMFC to start as soon as a power failure is detected.

Additionally the DMFC monitors the UPS battery voltage and also starts if the voltage drops.
This have been done to ensure that the DMFC would still be able to start if the serial cable were damaged or for some reason disconnected.

Certification

The DMFC UPS system was constructed using individually certifiable components.

However as an additional safety measure a HAZOP analysis was performed with help from DGC for the UPS system as a whole.

The HAZOP highlighted the need for a fuse to be inserted between the DMFC and the battery bank.

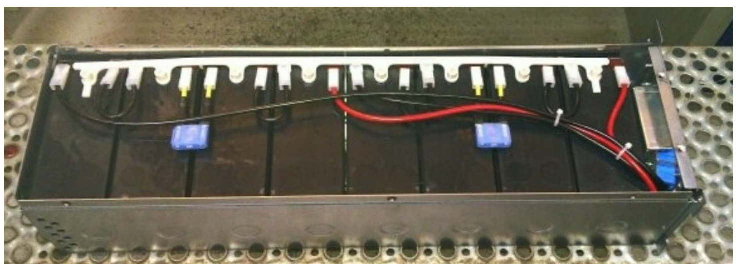


Illustration 15: The two fuses inside a battery module (2x per battery pack)

6 APC Smart-UPS XL 3000VA RM 3U 230V
7 2 battery packs together with the DMFC should suffice, however 3 was used in the design as a safety margin.
8 APC Smart-UPS XL 48V RM 3U Battery Pack

WP 4: IT UPS field test

Objectives

To select test sites for the UPS system field test. Preparation of the field test sites. Surveillance of the systems and data logging. In the following an overview of the main results are given.

Test site locations

For the field test the following 5 test locations where selected.

The test sites are located in the following cities.

- Andkær near Vejle
- Kolding
- Fredericia (2x)
- Middelfart

The test sites are all located relative close to Tre-For's headquarters in Kolding enabling easy access during the test period.

Illustration 16: Field Test Locations

Field test preparations

In order to accommodate the DMFC UPS systems the sites had to be prepared by Tre-For.
The modifications included the creation of holes for the 120mm exhaust and intake ducts, rerouting of electrical power to go though the UPS and vandal proofing the exterior of the intakes and exhausts.


Illustration 17: Exhaust and intake ducts


Illustration 18: Intake filter closeup

The UPS system was hocked up to one of the redundant power supplies in the POP station, the other redundant power supply was left connected to the regular grid.
This was done to prevent the UPS electronics from becoming a “single point of failure”.

Per recommendations by Tre-For technicians an air filter was installed on the intake and a grill on the exhaust.

In illustration 17 the exhaust and intake ducts can be seen, the exhaust duct is the longer one running in the foreground.
The shorter intake duct can be seen behind the exhaust.
On the intake a T-joint have been placed giving easy access to the air filter as seen on illustration 18.

Due to an incident of vandals setting fire to a POP station the intakes and exhausts had to be vandal proofed preventing flammable materials to be poured or inserted into the POP station.

Illustration 19: Prior to vandal proofing

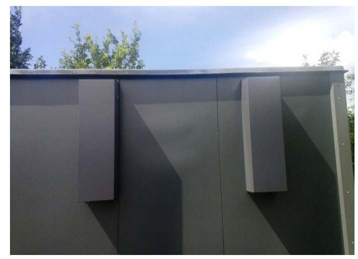


Illustration 20: After vandal proofing

Remote monitoring

Remote monitoring was done using a Linksys router with a custom firmware that allows encrypted secure access to the unit allowing IRD to download log files and access the unit remotely.
The router was also configured to allow Tre-For to access the units internal web page.

Illustration 21: Linksys router

Concerns about the test locations

Prior to the installation of the units there were some concern about frost.
I order for the units be capable of protecting them self a method for running with no electrical power output was developed.
However as this uses methanol which would be expensive to replace it would be beneficial if the units would be able to stay warm without entering frost protection mode.
However excessive use of methanol to keep warm was not found to be an issue.

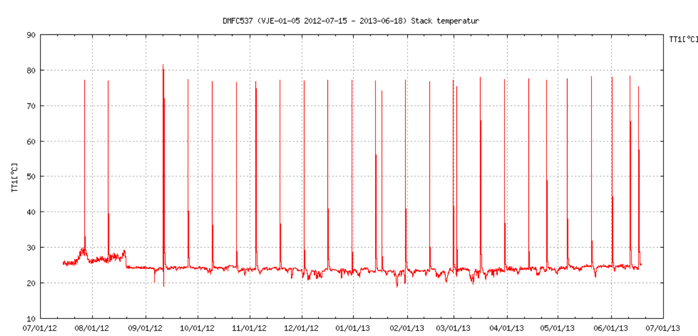


Illustration 22: Fuel cell stack temperature

Illustration 22 is a plot of the stack temperature for the unit in Andkær[9] which demonstrates that the

9 The other test site temperatures has a similar profile.

relative warm POP station[10] was capable of keeping the fuel cell well above freezing.

Lab test prior to installation

As the POP stations used as test sites were in active use Tre-For wanted to ensure that the system functioned correctly prior to installing them.
They therefor ran a load test on one of the DMFC UPS systems.

The test was done by connecting a AC consumer to the output of the UPS, disconnecting grid power and waiting until the UPS stopped providing power on the output.

2.2kW load test

While 2.2kW is more than the nominal load of 1.6kW the UPS used is capable of generating up to 3kW.
However as the load increases, the uptime drops non linearly.

The beginning of the test can be detected by the drop in the battery voltage (green), once the UPS stops outputting 230V AC the voltage jump up again.

At ~10:00 the test starts.

At ~11:45 the UPS powers down.

Which gives an uptime of approximately 1.8 hours.

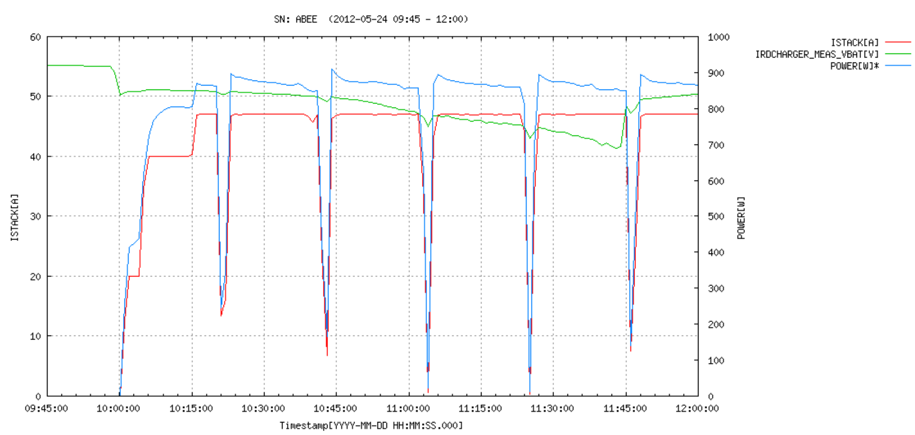


Illustration 23: 2.2 kW AC load

10 Normally the inside of the POP station is cooled even during the winter season.

1.5kW load test

At ~07:55 the test starts.

At ~10:35 the UPS powers down.

Which gives an up-time of approximately 2.7 hours.

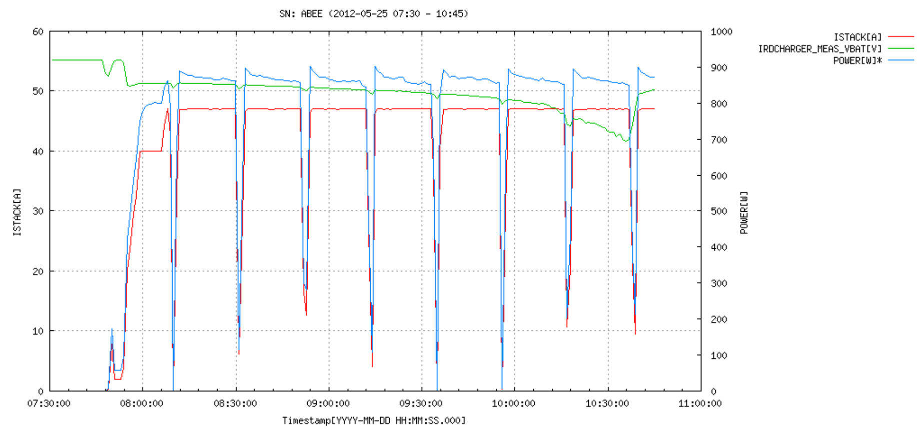


Illustration 24: 1.5 kW AC load

Field test

The DMFC UPS systems where successfully integrated in 5 existing POP stations, the systems where installed in 11 months as the primary backup solution.

During the field test the systems were remotely monitored and the systems performed automatic regular maintenance runs, the systems were also exposed to simulated power outages of different lengths and performed as expected.

During a real power outage the system also performed as expected and the POP station was not affected by the power outage.

The field test partner Tre-For considers the fact that it handled the unexpected grid failure correctly as the final seal of approval for the system.

Post test service

At the end of the field test, the DMFC generators were removed from the UPS systems and given a service and performance check.
The reason for this was two fold.

The primary reason was that the the lab tests of the DMFC didn't include two potential causes of degradation.

1. The low power maintenance startups that the system automatically performs in order to replenish its process water and killing bio grows.
2. The potential deterioration caused by exposure to atmospheric air while being idle.

Secondarily an overpressure safety valve was scheduled to be replaced[11].

The table below contains statistical information about the running of the DMFC generators during most of the test period[12].
The startups and runs includes all startups both automatic maintenance runs, manually initiated test and one real life power failure.

DMFC generator	**Number of startups**	**Run time[13] [h]**	**Methanol consumed[14] [l]**	**Liter/run time[15] [l/h]**
DMFC537 (SN: ABEE)	37	25	12	0.48
DMFC541 (SN: ABVQ)	30	15	6	0.40
DMFC542 (SN: ABVR)	31	18	7	0.39
DMFC543 (SN: AB43)	29	44[16]	18	0.41
DMFC544 (SN: AB44)	22	26	10	0.38
Total	149	128	53	

Table 1: Run statistics from 2012-07-15 to 2013-06-18

As part of the service checkup where the valve was exchanged the Factory Acceptance Test was redone. The logs were compared with the logs from the initial FAT prior to installing the DMFC units.

During the field test the systems have been operational for at total of 39600 hours.

System performance was found to be unchanged after the field test compared to the initial performance.

11 Due to lack of practical knowledge or manufacture guaranties with regard to functional life expectancies a low service interval had to be specified.
12 The time period has been limited to the given range in order ensure that no production and service data is included.
13 The run time includes startup, refresh cycles and shutdowns as well as the primary energy producing state.
14 Based on the internally calculated fuel consumption by integrating methanol pump flow
15 Lower than the nominal fuel consumption due to the fact that the maintenance runs doesn't require as much fuel as normal operation as well as the way runtime is measured.
16 The DMFC was unintentionally connected to a empty battery bank when first installed causing some additional runtime compared to the other units.

WP 5: Evaluation

Objectives

The objective of this task is to evaluate the UPS system and the APU system both with respect to the application and the overall system cost. In addition three prototype test partners will be identified and a business plan will be made.

3G DMFC cost analysis

The cost target for the project was 9000€/kW under the assumption that 1100kW of modules where produced on an annual basis.

During the duration of this project several field test units where produces and a detailed cost study has been made. In addition a study of potential module enclosures and frameworks was made with respect to production costs and end user feedback. Finally an evaluation of the economy of scale was made when going from a 6 unit series for field test to mass production on the order of 1000 units a year.

All together these studies showed that that a module price of 9000€/kW was possible.

External Test Partners

In order to increase the knowledge gained about the market and the exploitation of the project potentiall it was agreed upon that IRD should find 3 additional unfunded test partners for the DMFC technology.

Three partners where identified each with different requirement with respect to runtime, environmental challenges and demand to reliability.

Partner 1.

Partner 1 is testing the DMFC as Tertiary power source for critical power supply in remote locations.

Light houses and buoys in remote locations is an example of this critical power supply.

Currently the power is supplied by solar and wind as primary power source and a backup diesel generator, this setup does however have its drawbacks and the addition of a third different technology will increase reliability of the existing setup.

Illustration 25: The island Lismore off the coast of Scotland

However the sites where the generators are located are often only reachable by boat thus a simple oil change becomes relative expensive. Thus there is a demand for a DMFC APU that can replace the diesel generator to provide better self reliance and longer service intervals, leading to great savings in service costs.

Partner 2

Partner two specializes in providing off grid solutions in remote and cold areas and is testing in these environments.

Current installations are based on solar, wind and batteries, thus 100 % percent availability is not possible. With the addition of a DMFC generator 100% availability is possible.

Also as these installations are often located in remote areas accessible only by helicopter and only when the weather permits, the energy density of the fuel and the system self reliance is of paramount importance.

Illustration 26: Norwegian technicians servicing a telecommunication tower on a mountain peak 1600m above sea level

Partner 3

Partner 3 specializes in energy supply solutions.

This partners is currently testing the DMFC as run time extension for UPS installations, due to increased backup time(5 days +) requirements for critical radio services. In this case the system must be a drop-in replacement in already existing UPS installations, that range from 0-4000 meters and from remote to urban environments. In this case the easy fuel handling and small footprint is making the DMFC competitive to the other options(batteries or diesel generators.)

The test partners provided access to various test environments, two examples are tests above 3000 meters in altitude and tests under severe weather like snows storms and prolonged periods of frost.

In addition test at the respective partners have provided valuable information about the DMFC module and how the system is optimally integrated in end user installations.

Finally the test partners have provided valuable information about new potential markets

Exploitation

The knowledge gained from the field test at Tre-For, the test at DGC and the tests at external test partners will be exploited by IRD to further commercialize the DMFC systems, not only for the UPS market but also for the more demanding markets like power in remote and inaccessible areas.

DGC intends to exploit the knowledge to test and certify fuel cell based technologies.

Finally a patent has been applied for by IRD to protect the IP that was developed in the project.

Conclusion

- The IT UPS systems was found to be capable of delivering the up time in accordance with the specification.
- The DMFC units required no parts to be replaces during the entire field test period.
- The DMFC units have been successfully integrated into the POP stations.
- As part of the exploitation direct result of the market feedback from the additional test partners the DMFC have been tested at elevations significantly higher than the original specification.
- Tre-For has expressed its overall satisfaction with the DMFC UPS systems and considers the fact that it handled the unexpected grid failure correctly as the final seal of approval.
- The market in general has shown interest for the technology, especially for the more demanding APU applications.
- Finally the DMFC module was evaluated against the 2014 danish roadmap targets with respect to cost, efficiency and stack lifetime. The targets for stack lifetime and system efficiency were proven whereas the target for system cost had to be extrapolated from the cost analysis of the few prototypes produced in the project.