Final report
Local Energy Storage

64014-0506

Norlys Holding A/S
Lithium Balance
DTU Elektro
PA Energy
FLUX
Spøttrup Kulturhal

1. Project details

Project title	Local Energy Storage (LES)
Project identification (program abbrev. and file)	64014-0506
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Norlys Holding (tidligere Eniig/EnergiMidt) Tietgensvej 4, 8600 Silkeborg
Project partners	Norlys Holding, DTU Elektro, FLUX, Lithium Balance, Spøttrup Kulturhal, PA Energy
CVR (central business register)	39072793
Date for submission	30. juni 2020

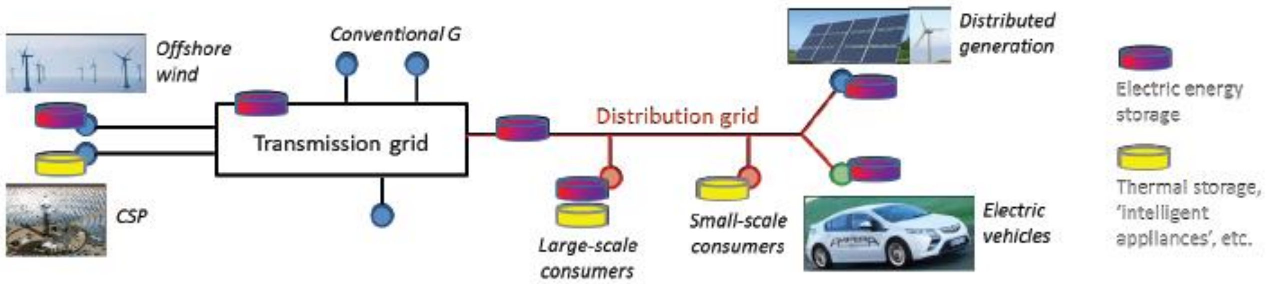
2. Indhold

3. Short description of project objective and results

The project aims at investigating the feasibility of energy storage application on grid power quality improvement due to arising renewable energy penetration in the grid.

Traditional solution for grid power quality improvement contains PV power output curtailment, grid reinforcement, reactive power generation and so on. However, these solutions are either damaging the site owner's profit or too costly.

The "Local Energy Storage" (LES) project develops local energy storage to enable higher local production of renewable energy, make the user take full advantage of own electricity production and last but not least stabilize feeder lines in the low voltage area as more and more renewable energy is injected to the grid. The LES project will cover and could solve several specific arising problems in the utility network, also improving the economy in installed PV-systems and will demonstrate new business opportunities.



A more energy efficient PV retrofit technology development is also part of the project objective. Part of the PV generation losses come from the DC/AC inverter. In order to capture more power from the PV generation, power electronic platform based on a four-port DC-DC converter will be established that is able to charge batteries from PV directly as well as support any local DC loads such as LEDs without multiple power conversion stages; therefore, system efficiency can be improved and cost can be accordingly reduced.

As a result, grid utility demonstration has been done at Spøttrup Kulturhal which is located in Skive municipality. The 75 kWp rooftop PV has paired with a 79 kWh energy storage system provided by Lithium Balance. Two operational mode has been performed on site: max self-consumption and voltage support. Result of these two operational modes are positive and has been documented in the Appendix D6.3.

Furthermore, a DC-DC converter has been developed with which as cost and energy efficient way to connect a battery to a solar system. The envisioned system would tap in on the electrical connection between the solar panels and inverter that transforms the DC generated power form the panels to the public electrical grid. Such as system could simplify the way battery storage is installed on existing residential solar systems.

Around 100.000 solar systems are currently installed in Denmark, many of these have been installed at a time where high incentives where given, the owner got the same price for the generated energy as they would pay, essentially using the grid as the storage. As the solar panels generate energy during the day, but most households use their electrical energy during the morning and evening. Many of the incentive programs have now been scaled back leaving the solar panel owners with a less attractive business case, a local battery could change this.

A scaled down test version, approximately 1/3 size was designed, produced and tested, this showed that the principle works and has potential. But it also showed that the interfacing to the inverter is problematic and will require more design work to universal to all types of installations with different brands of solar inverters.

4. Kort beskrivelse af projektet og resultater

Projektets formål er at undersøge, om det er muligt at anvende batterier til at forbedre spændings-kvaliteten i elnettet, når der installeres mere vedvarende energi.

Traditionelle muligheder og løsninger til af forbedre spændingskvaliteten i elnettet er at begrænse power input fra solcelleanlæg, forstærkning af nettet, reaktiv elproduktion osv. Disse løsninger giver imidlertid enten en dårlig privat økonomi eller er for dyre.

”Local Energy Storage” (LES) -projektet udvikler styringselektronik til at lagre energi lokalt og dermed muliggøre en højere decentral produktion af vedvarende energi. Projektet giver private kunder en højere udnyttelsesgrad af solcellerne og ikke mindst stabilisere det udføringerne i lavspændingsområdet efterhånden som mere og mere vedvarende energi fødes ind på nettet lokalt. LES-projektet vil afdække og kan løse flere specifikke udfordringer i elnettet, hvilket også forbedrer økonomien i de installerede solcelleanlæg og vil demonstrere nye forretningsmuligheder.

En mere energieffektiv udvikling af PV-retofit-teknologi er også en del af projektets målsætning. En del af PV-produktionstabene kommer fra DC/AC-inverteren. For at øge effektiviteten af solcelleanlægget, oprettes der en power elektronisk platform baseret på en fire-ports DC-DC-konverter, der er i stand til at oplade batterier fra PV direkte, samt understøtter lokale DC-belastninger, såsom lysdioder uden multipel strøm konverteringstrin. Derfor kan systemeffektiviteten forbedres, og omkostningerne kan reduceres i takt hermed.
Som et resultat er der demonstreret et nettilsluttet batteri i Spøttrup Kulturhal, der ligger i Skive Kommune. Et 75 kWp PV-anlæg på taget er parret med et 79 kWh batteri system leveret af Lithium Balance. To operationelle styringer er blevet demonstreret på stedet: maksimalt egetforbrug og spændings-understøttelse. Resultatet af disse to driftsformer er positivt og er dokumenteret i Appendix D6.3.

Derudover er der udviklet en DC-DC-konverter, som dokumenterer en omkostnings- og energieffektiv måde at tilslutte et batteri til et solcelle anlæg på. Det planlagte system ville tappe ind på den elektriske forbindelse mellem solcellepaneler og inverter, der omdanner den jævnstrømsgenererede strøm fra panelerne til det offentlige elnet. Sådan et system kan forenkle den måde, hvorpå batterier installeres sammen med eksisterende solcelleanlæg.
Cirka 100.000 solcelleanlæg er nu installeret i Danmark, mange af disse er installeret på et tidspunkt, hvor der var høje feed-in tariffer. Der var årsnettomåling, hvor ejeren fik den samme pris for den producerede energi, som for den aftagne, og elnettet blev brugt som lager. Solcelleanlæg producerer energi i løbet af dagen,

mens de fleste husstande bruger energi om morgenen og aftenen. Alle solcelle afregnings-modellerne er nu blevet nedskaleret/lukket, hvilket efterlader ejere af solceller med en mindre attraktiv forretningsmodel. Et lokalt batteri kan ændre dette.

En nedskaleret testversion, ca. 1/3 størrelse, blev designet, produceret og testet, dette viste, at princippet fungerer og har potentiale. Men det viste også, at interfacet til inverteren er problematisk og vil kræve mere designarbejde for at være unikt for alle typer installationer med forskellige mærker af solcelle invertere.

5. Executive summary

The project has demonstrated the utility storage solution and a more efficient DC-DC converter for existing PV installation retrofit. The utility storage application has advantages on its flexibility and scalability. It is also to be expected more cost friendly compare to conventional grid strengthening.

The battery DC-DC converter for possible refit to existing solar panel systems is doable and has the potential reducing the cost associated adding battery storage to existing systems, but that the development would need more time to get a universal solution that fit majority of older systems.

6. Project objectives

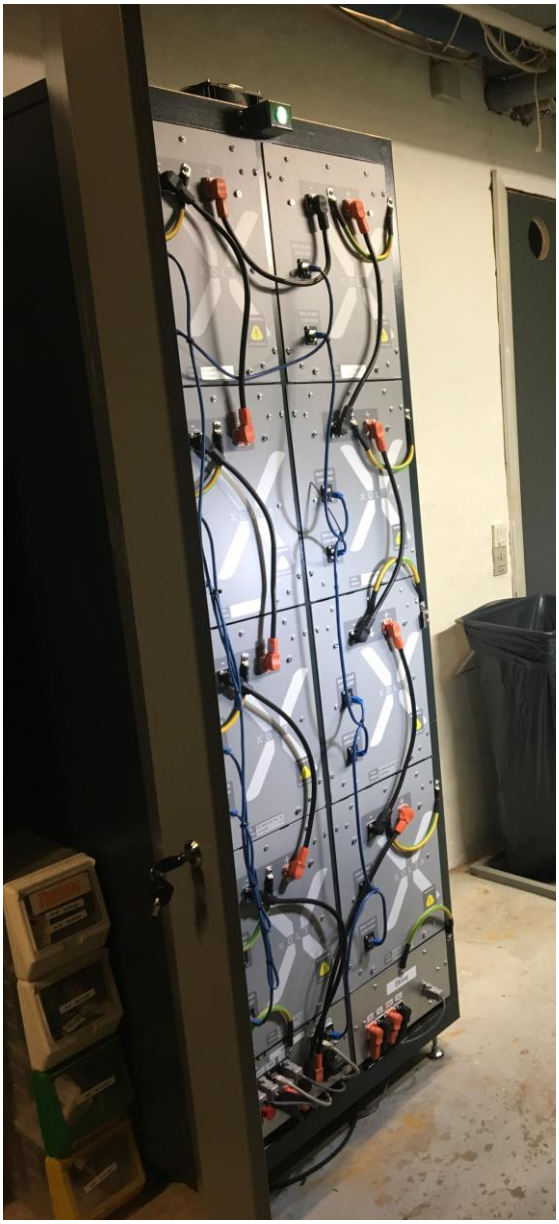
The project aims at investigating the feasibility of energy storage application on grid power quality improvement due to arising renewable energy penetration in the grid. Two ways are investigated:

- Local grid reinforcement by placing a storage system in close proximity to the last distribution transformer which can support the grid radial which may occur short periods of overload, because households connected have installed PV systems and/or heat-pumps replacing old oil or gas furnaces and perhaps also have invested in electrical cars. All which put and extra strain on the grid for which it was not designed for.
- Explore a simple way implementing storages at each household which has gotten PV already and thereby eliminating the peak demands from each residence both in view of consumption and generation from the PV which affect the electrical grid if excess power is pushed into the grid.

The “Local Energy Storage” (LES) project develops local energy storage to enable higher local production of renewable energy, make the user take full advantage of own electricity production and last but not least stabilize feeder lines in the low voltage area as more and more renewable energy is injected to the grid. The LES project will cover and could solve several specific arising problems in the utility network, and also improving the economy in already installed PV-systems and will demonstrate new business opportunities.

6.1 The Grid-size testsite

The grid utility demonstration has been done at Spøttrup Kulturhal which is located in Skive municipality. The 75 kWp rooftop PV has been paired with a 79 kWh energy storage system provided by Lithium Balance.



There were some difficulties in finding this location, due to changes in installing PV-systems for municipalities; another testsite was chosen prior but had to be abandoned since the PV had to be de-coupled from the grid due to legislation issues, which gave some delays.

Two operational modes have been performed on site:

- max self-consumption and
- voltage support.

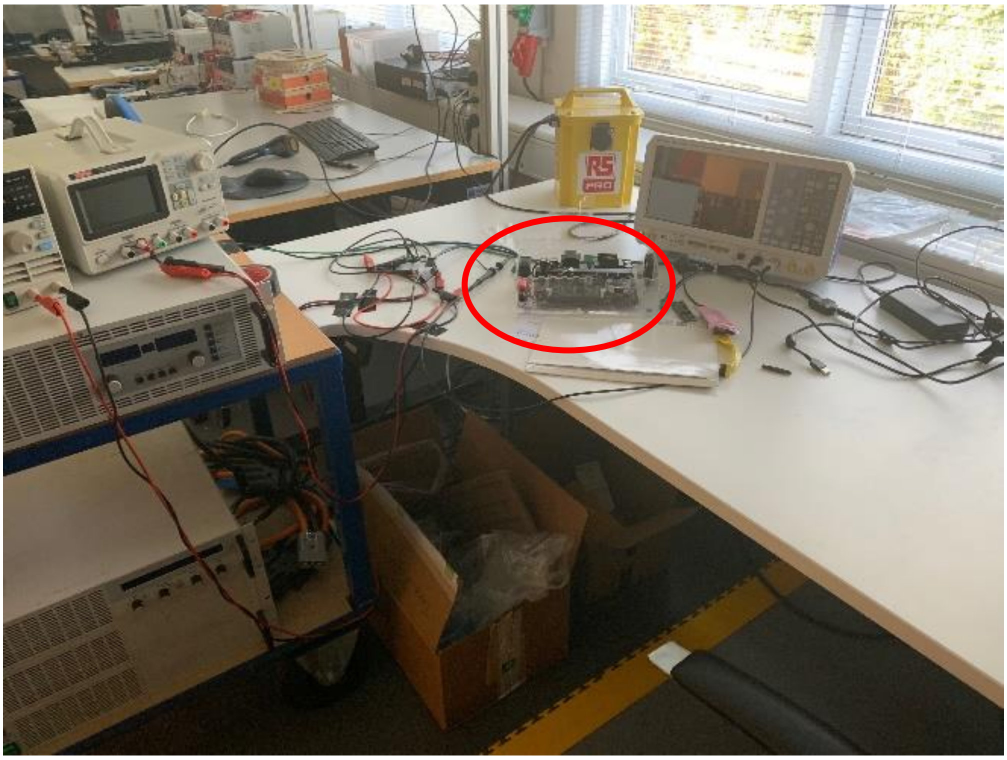
Result of these two operational modes are positive, see more in chapter 7.

6.2 PV-retrofit

A more energy efficient PV retrofit technology development is also part of the project objective. Part of the PV generation losses come from the DC/AC inverter. In order to capture more power from the PV generation, power electronic platform based on a four-port DC-DC converter will be established that is able to charge batteries from PV directly as well as support any local DC loads such as LEDs without multiple power conversion stages, therefore;

system efficiency can be improved and cost can be accordingly reduced.

A DC-DC converter has been developed which has a cost and energy efficient way to connect a battery to a solar system. The envisioned system would tap in on the electrical connection between the solar panels and inverter that transforms the DC generated power form the panels to the public electrical grid. Such as system could simplify the way battery storage is installed on existing residential solar systems.



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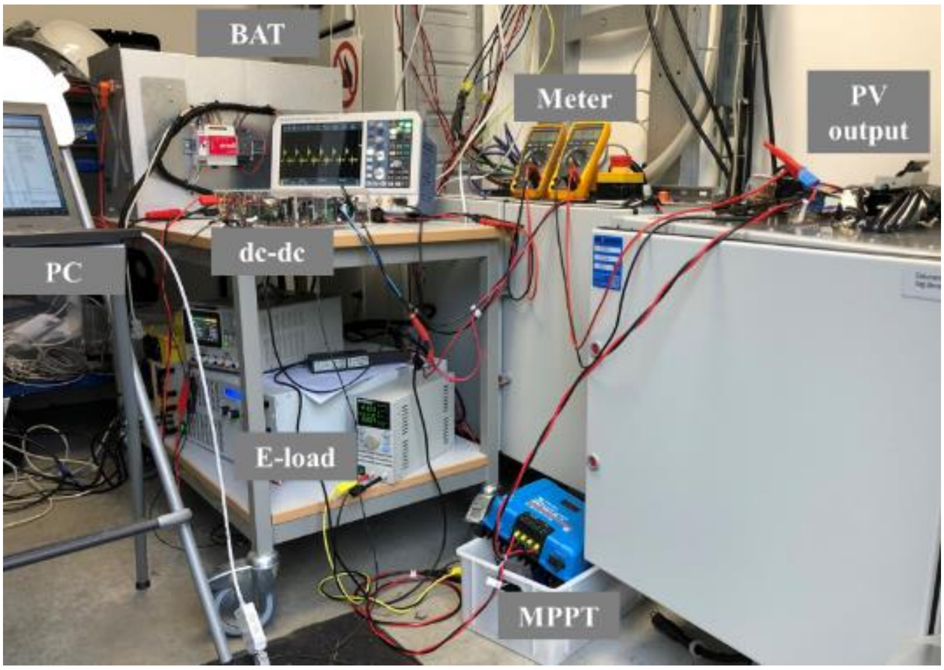


The technical issues encountered, interfacing to solar inverter, meant that many more development hours than planned is needed and delaying the implementation.

Prototype testing at residential homes had to be omitted due to time limitations and technical issues. The scale version was testes in a simulated setup at Lithium Balance laboratory where a scale PV and household consumption were installed (see picture above).

7. Project results and dissemination of results

7.1 Main activities.

- Battery system with a DC-DC converter:
  - Several prototypes where build
  - The concept principle works
  - Interfacing to a variety of different brand of solar inverter is a challenge
- Utility storage
  - Site chosen

    The site chosen has faced some issues. The original site location was declined in the middle of the project due to the disagreement of the battery installation. Therefore, the task has been delayed for some months. This has been also documented in annual report 2019.
  - Dimensioning

    The dimensioning work is done by Lithium Balance and Eniig together. It is based on the new site; Spøttrup Kulturhal
  - Installation

    The installation process is much slower than expected, due to the bad communication with the electrician on site.
  - Testing

    The testing period goes smoothly. Once we found out the site does not have any voltage issue, we quickly found a new strategy for the test plan.

7.2 DC-DC converter technical result

<u>Scope</u>

Upon development of the bidirectional DC/DC converter prototype, the aim with this test, is to verify the feasibility of implementing the device in a laboratory supported application.

The DC/DC converter is bidirectional, within the limitations set by the hardware design of the device.

The device can operate in one of three modes:

1. IDLE with no operation
2. CHARGE, directing energy sourced from a PV array to a battery energy storage
3. DISCHARGE, directing energy from a battery energy storage to assist weak PV output or solely support entire load

Mode selection is performed via a PC operated CAN communication channel.

<u>Purpose</u>

The purpose of the test is to show feasibility of the DC/DC converter in a laboratory controlled live environment, this means that the DC/DC converter demonstrates intended functionality in the possible modes of operation during varying conditions of load and solar PV supply.

<u>DC/DC converter hardware design limitation:</u>

- Mode change
  - Alternating the CHARGE / DICHARGE modes, requires coupling of the battery / PV through passive separating rectifiers, this to prevent destructive high current inrush spikes to the DC/DC converter semiconductors during startup and hence large voltage difference.

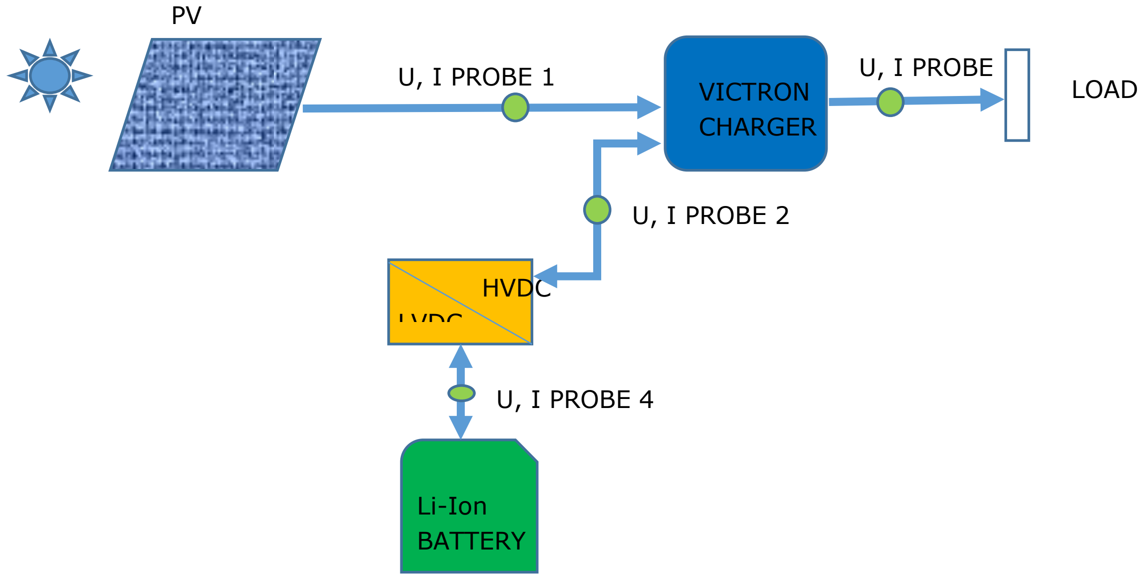
- The rectifiers ensure that the converter couples only at a safe voltage difference.
- In CHARGE mode, the rectifier is placed between the battery and the DC/DC converter
- In DISCHARGE mode, the rectifier is placed between the DC/DC converter and the PV array.
- In a commercial system, this functionality will be performed by the separating safety relays.

- **Current limitation**
  - The controlling device (microcontroller) of the DC/DC converter shows susceptibility to switching noise during high current operation, this may result in unpredictable states of the controlling device and hence destructive behavior to the power semiconductors. Due to this fact the allowed power is limited to less than 200 W

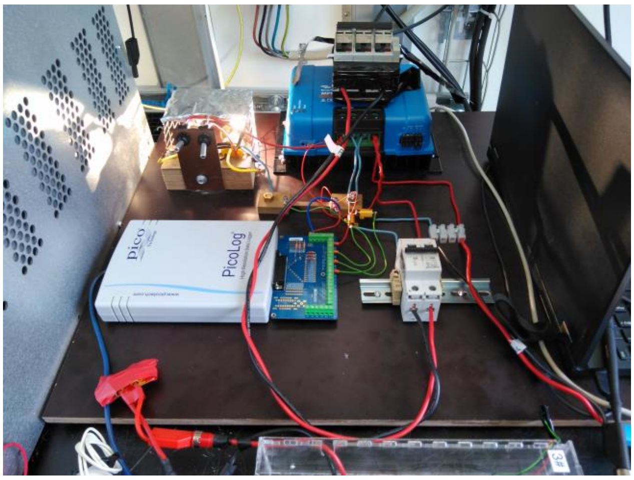
Test setup

The test setup includes following components and units:
Local Energy Storage bidirectional DCDC converter
PV array (3 pcs. VICTRON SPP032602000 164 X 99.2 [cm] in series), output voltage 100 V DC 260 W max
PV charger, Victron MPPT 250 I 60 – Tr
Multistage ballast load (2 X automotive lamps 12V 60W)
Current measure shunt resistors
PICOLOG ADC24, data logger
PICOLOG connection board
48 Volt 100 Ah Lithium Ion battery

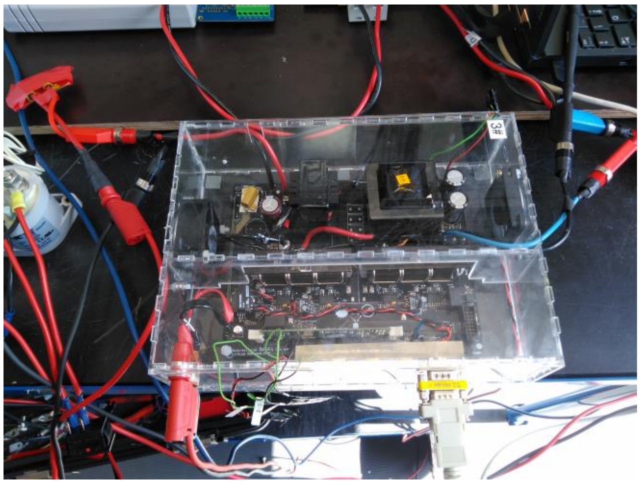
Test setup block schematics



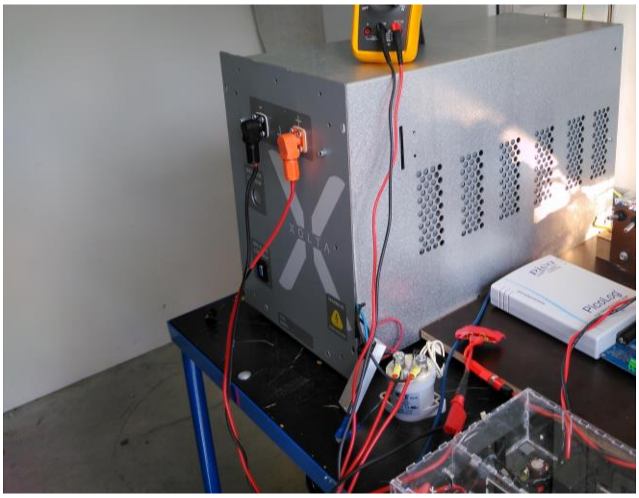
Physical test setup



Picture showing the test setup with active lamp load and the PICOLOG datalogger connected to monitor voltages and currents



Picture showing the LES DCDC converter prototype connected



Picture showing the 48 Volt 100 Ah Lithium Ion battery connected to the LES DCDC converter

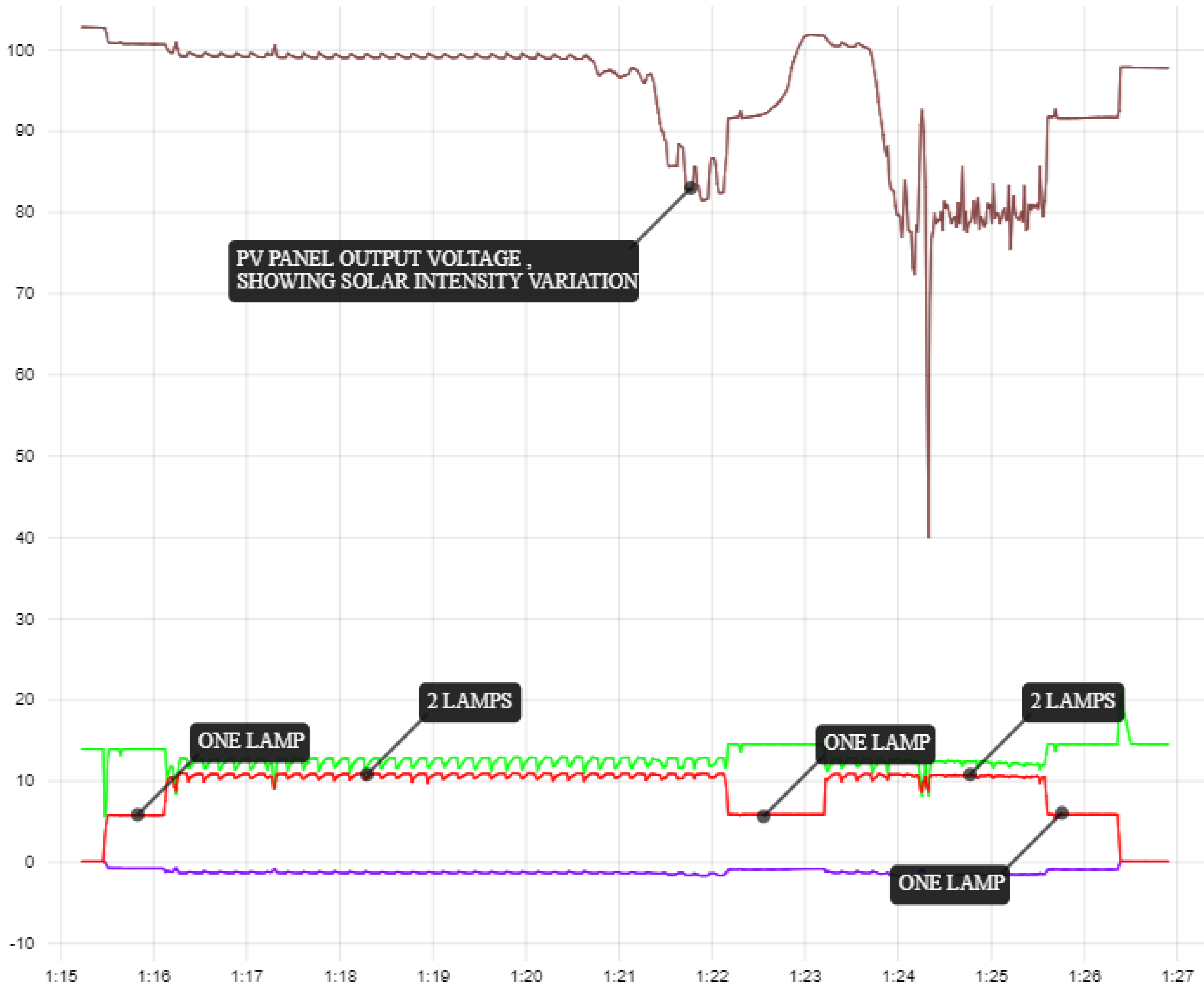
Picture showing the PV array used in the test

DC/DC converter test results

Measurement 1. Ordinary PV load

Voltage and current are monitored and recorded for representative period of time for the PV output and the Load. (Probe 1 and Probe 3)

The load is varied over time during the test, to provide fluctuating consume.



Graph legend:

Brown: PV voltage
Green: MPPT load voltage
Red: MPPT load current

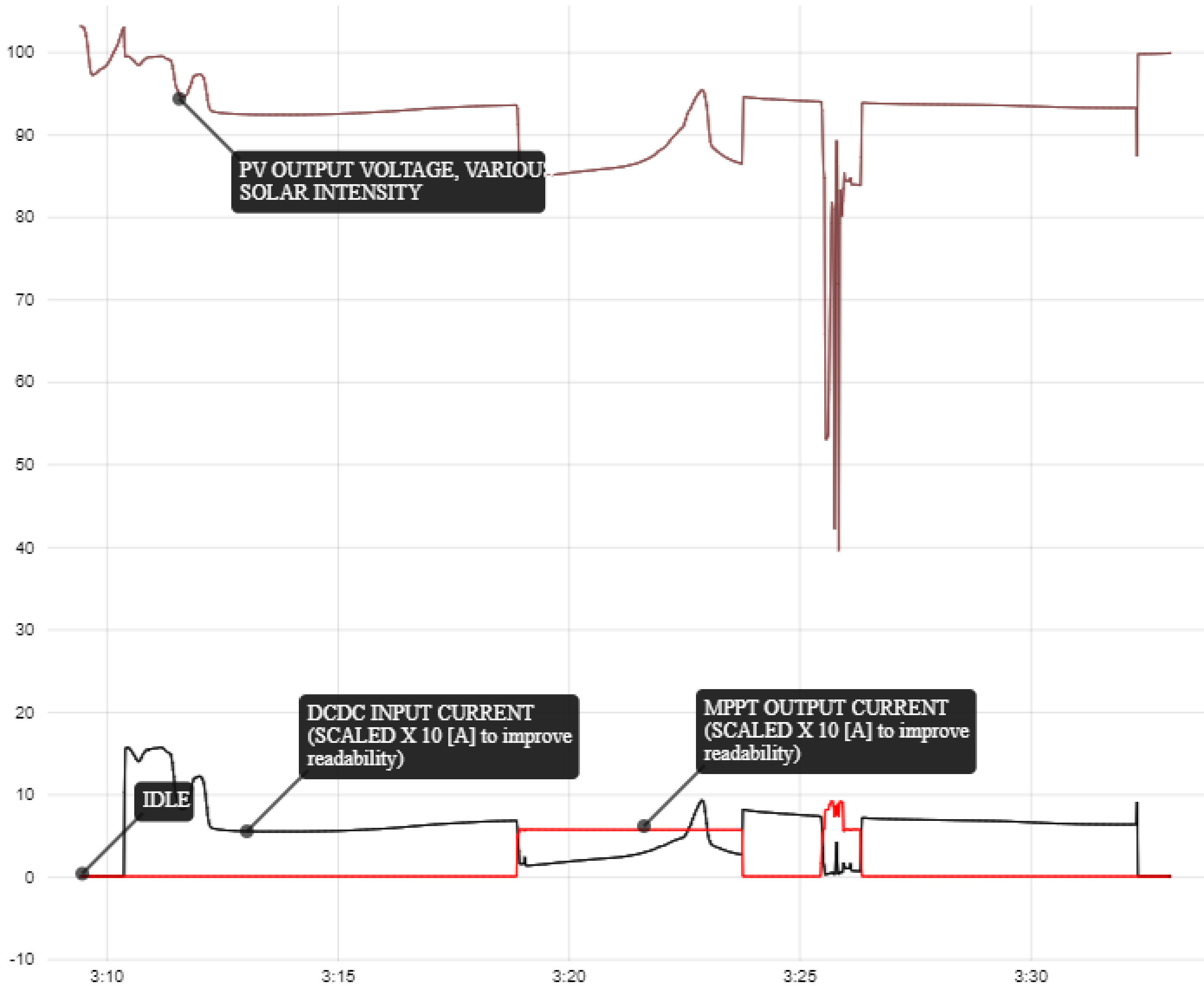
Note that the current and voltage fluctuates even during stable PV input, this is caused by the MPPT, that regulates to obtain the Maximum Power Point.

Measurement 2. Battery charge HV side

The DC/DC converter is set to Battery Charge mode, performing charge during energy PV surplus.

Voltage and current are monitored and recorded for representative period of time for the PV output, the DC/DC HV current input and the MPPT load current. (Probe 1, Probe 2 and Probe 3)

The MPPT load is varied over time during the test, to provide fluctuating consume on the PV side.



Graph legend:

Brown: PV voltage
Black: DCDC converter input current (Battery charge current @ High voltage side)
Red: MPPT load current

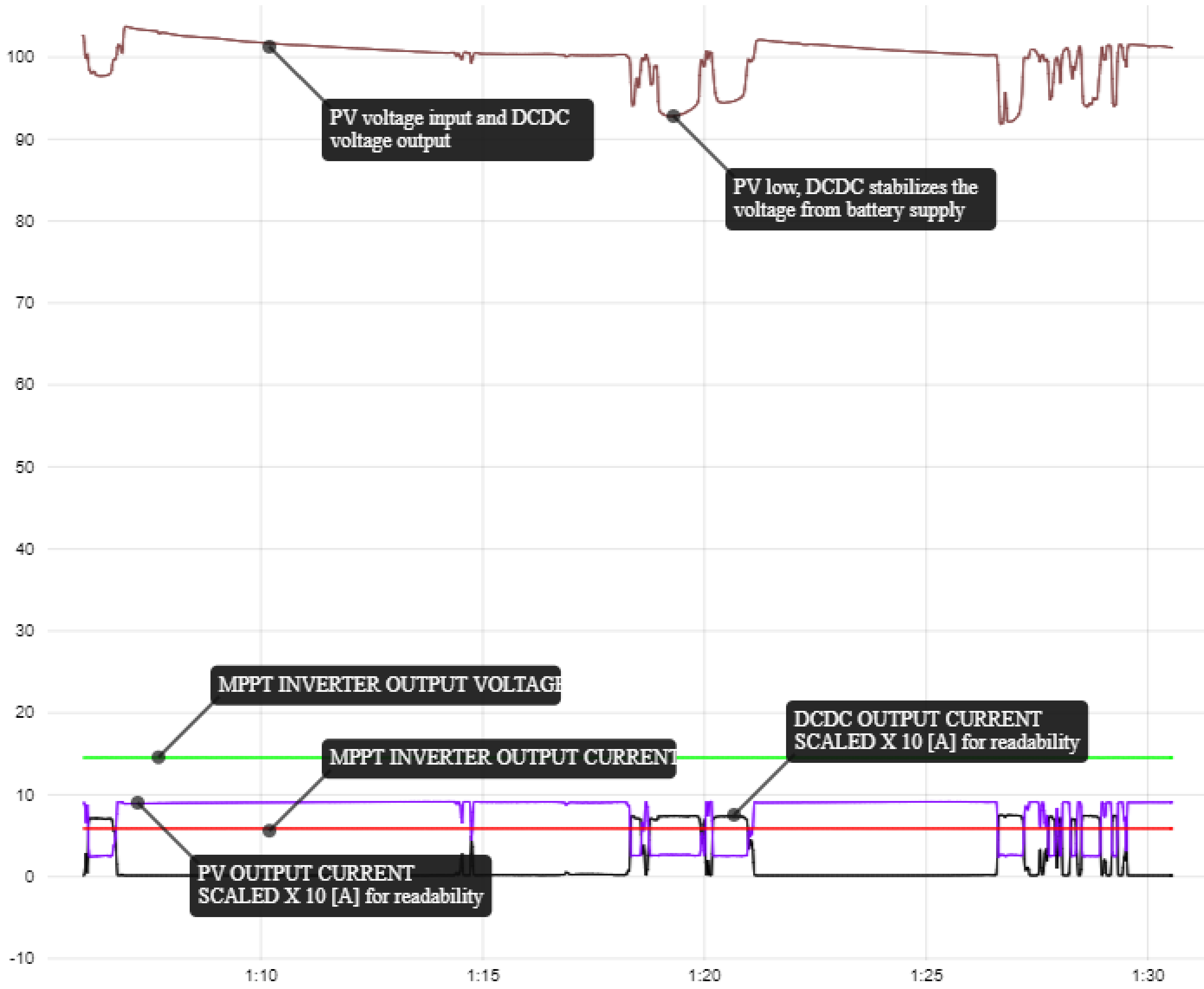
Note the priority of the current drawn, with respect to the PV input the load is favorized and the surplus goes to the battery charge.

Measurement 3. Battery assisted PV load

The DC/DC converter is set to Battery Discharge mode, performing discharge to assist weak PV output.

Voltage and current are monitored and recorded for representative period of time for the PV output, the Load and the DC/DC HV output. (Probe 1, Probe 2 and Probe 3)

The PV output is varied over time during the test providing fluctuating PV supply.



Graph legend:

Brown: PV voltage
Black: DCDC converter sourcing current
Red: MPPT load current
Purple: PV output current

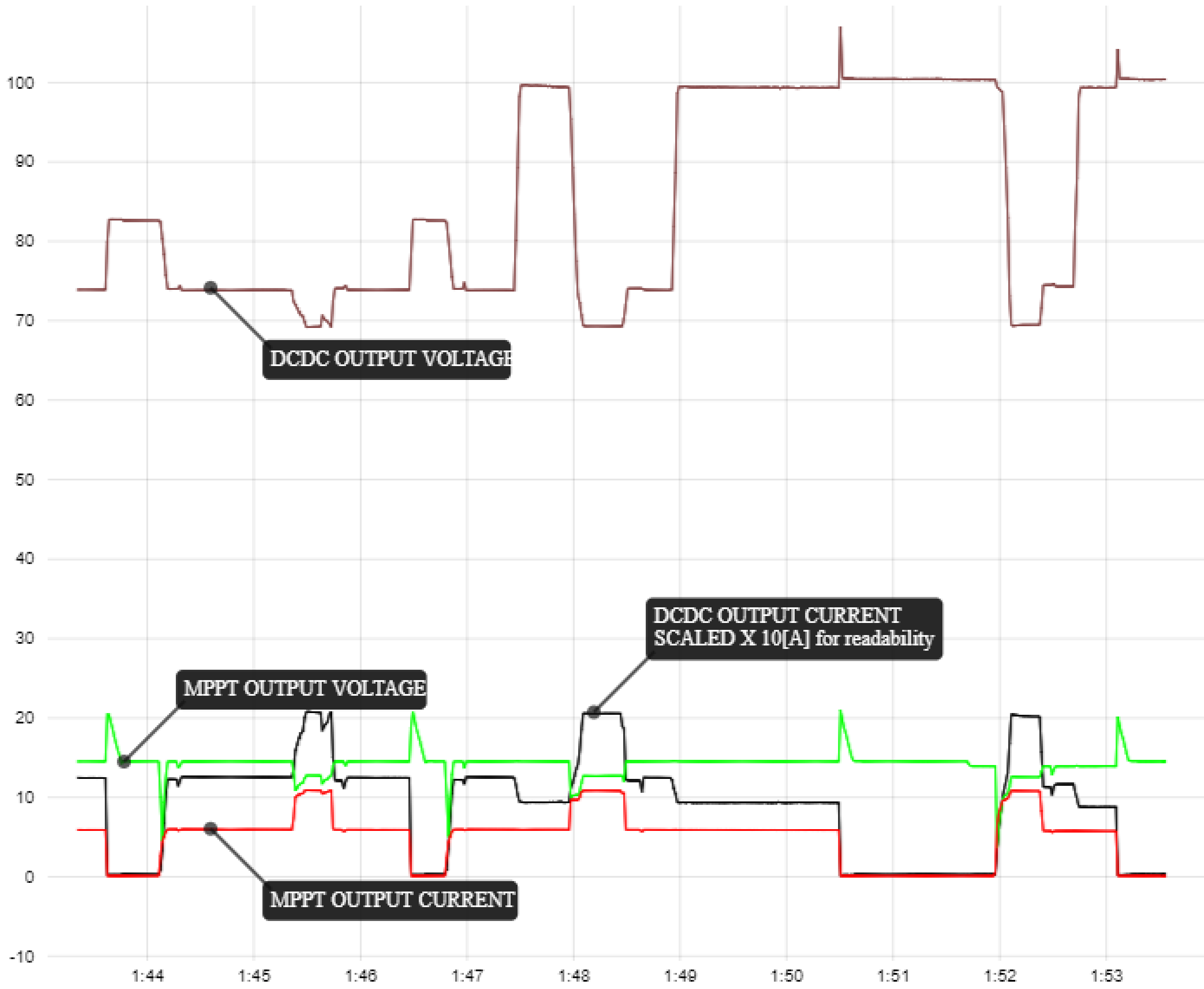
During the fluctuating PV input, the DCDC converter supplies assisting power to maintain the stability of the MPPT output. The PV input drops in periods with low solar radiation and the DCDC converter maintains the voltage.

Measurement 4. Battery driven load

The DC/DC converter is set to Battery Discharge mode, performing discharge to solely supply the load.

Voltage and current are monitored and recorded for representative period of time for the Load and the DC/DC HV output. (Probe 2 and Probe 3)

The load is varied over time during the test, to provide fluctuating consume.



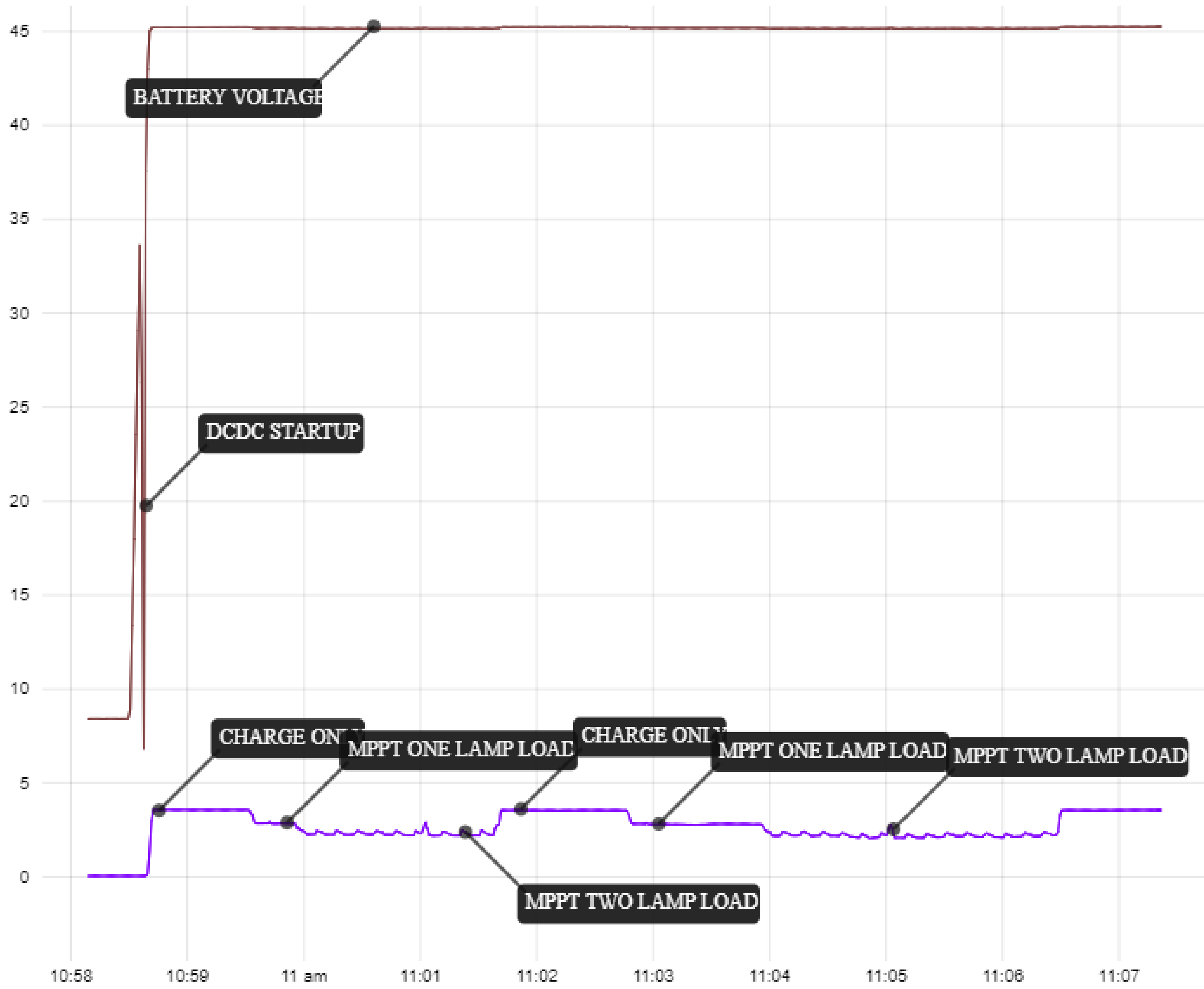
Graph legend:

Brown: DCDC output voltage
Green: MPPT load voltage
Red: MPPT load current
Black: DCDC converter sourcing current

Note the effect of the MPPT operation, this causes to vary the load of the DCDC converter and hence the output voltage of the DCDC. The DCDC converter aims to maintain a constant voltage with a current limit, and the MPPT varies the input condition to optimize. This shows in the fluctuating DCDC output voltage.

Measurement 5. Battery charge LV side

Due to galvanic isolation issues with the logging equipment (PICOLOG ADC 24) it is not possible to do simultaneous measurements on the HV and LV side of the circuit.
The DC/DC converter is set to Battery Charge mode, performing charge during energy PV surplus
Voltage and current are monitored and recorded for representative period of time for the battery. (Probe 4)
The MPPT load is varied over time during the test, to provide fluctuating PV supply.



Graph legend:

Brown: DCDC supplied battery voltage
Purple: Battery charge current with various power available from the PV

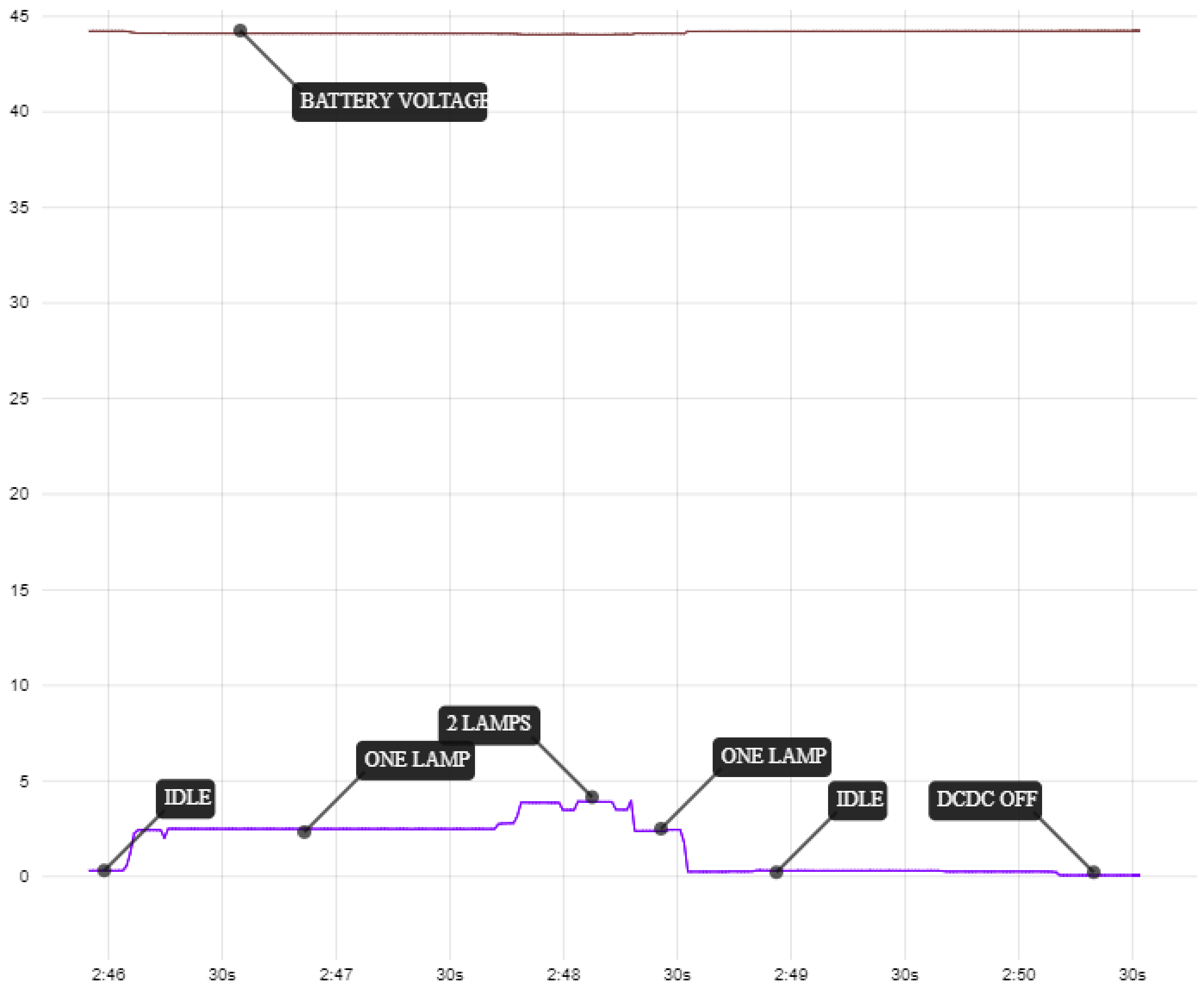
Depending on the MPPT load, the battery charge current is prioritized to favorize the supply of the MPPT load.

Measurement 6. Battery discharge LV side

Due to galvanic isolation issues with the logging equipment (PICOLOG ADC 24) it is not possible to do simultaneous measurements on the HV and LV side of the circuit. The DC/DC converter is set to Battery Discharge mode, performing discharge to solely supply the load.

Voltage and current are monitored and recorded for representative period of time for the battery. (Probe 4)

The load is varied over time during the test, to provide fluctuating consume.

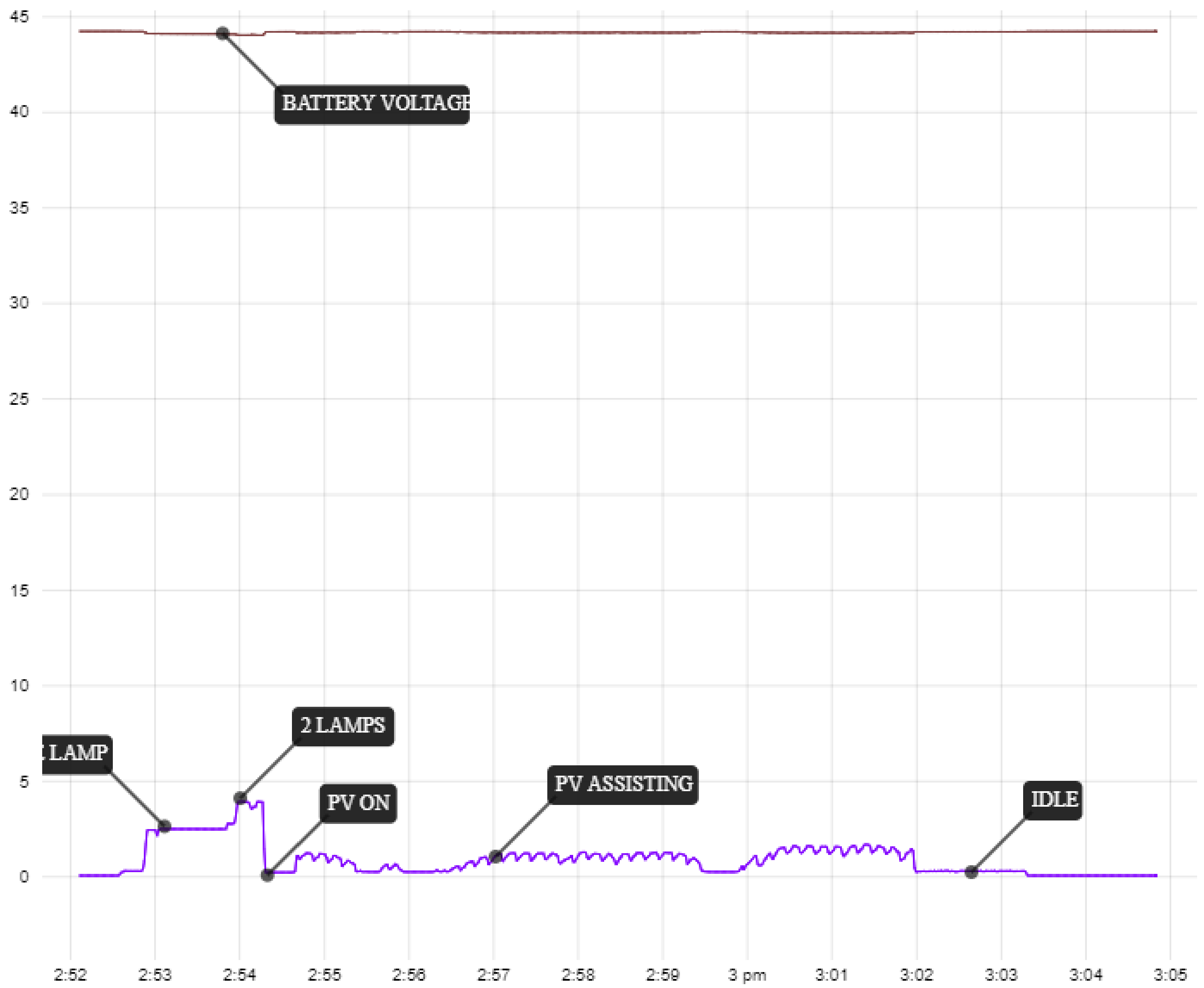


Graph legend:

Brown: Battery voltage supplying the DCDC converter
Purple: Battery discharge current with various load of the MPPT

The DCDC converter solely supplies the MPPT load

Adding the PV supply to the MPPT, thus paralleling the DCDC converter and the PV to support the MPPT load has following graph



Graph legend:

Brown: Battery voltage supplying the DCDC converter
Purple: Battery discharge current with various load of the MPPT, supported by the PV

Initially the DCDC converter supplies solely the MPPT load, after connecting the PV (PV ON) the discharge current from the battery decreases to only supply the excessive need for assisting the PV to maintain the MPPT load.

<u>Evaluation and conclusions on the Local Energy Storage DC/DC converter.</u>

Developing the bidirectional DC-DC converter for LES has revealed both possibilities and challenges.
To commercialize the DC-DC converter for domestic use, several issues must be taken into consideration.
Hereunder the great variety of the properties of commercial available solar inverters, mainly the ability to track power from the PV, may result in regulator conflicts between the Inverter and the DC-DC converter, causing excessive fluctuating performance of the DC-DC converter.

Product maturing into handling the automated alternating coupling between charge and discharge of the battery requires additional controlling devices, monitoring the system parameters in order to provide stable operation of the different modes.
During the operation of the DC-DC converter prototype, it has become obvious that there is need for an improved construction regarding the PCB layout, the present layout is sensitive to noise induced by the inductive and switching components. As a result, this can cause the controlling device to malfunction and have destructive effect on the switching power components. An improved PCB layout will have a positive effect in both the susceptibility to noise, and also improve the power throughput capability to meet the initial target specifications of 1000 W.
Concluding on the observations and tests, it is indeed feasible to commercialize the product taking the above into the equation. Mainly an improved PCB design and automation of the mode change will make it possible to develop a unit easy to implement in existing PV installations.

7.3 Utility storage technical result

Description

Grid utilities use case: one of the concerns in Spøttrup area is that the 10/0.4 kV transformer can only be manually operated, it means that it cannot maintain the voltage in the safety operational level in case there is too high renewable production or heavy load. With the increasing of PV installation in the grid, DSO will have to face over voltage issue more often. The grid facilities will have to be upgraded for strengthening the grid. "Voltage control at grid side storage" demonstrate a 79-kWh storage which installed close to the transformer secondary side can follow DSO's instruction and work as a voltage support unit to maintain the local voltage stability.

Evaluation procedure

The evaluation of this use case starts by monitoring the normal voltage fluctuation at the PCC (point of common coupling) of the premise. A reference voltage is then decided based to the observation. According to the load type and local grid situation, a droop control curve based on active power is designed and then applied to the local ESS control unit (site controller). When activate the ESS to "Voltage support" mode, the control algorithm will start running and regulates the voltage towards the reference.
From user's point of view, the only action needed is to start the ESS and select "Voltage support" mode. The regulated voltage should stay within safety operational range of 230V±10%.

Evaluation results

The test start in late March and finished by April. The total testing time takes around 2 weeks, as it is a prove of concept demonstration. Moreover, voltage support is not in the interest of the site owner, since currently there is no subsidies which have applied to LV grid in Denmark for performing voltage support applications. In this case site owner lose profit by running ESS in voltage support mode for long period of time. Since then it is decided to run the test as short as possible until a valid result can be extracted and presented.
The test started with one-week observation of the local grid demand, PV production, and the overall voltage fluctuation range as shown in Figure 1 and Figure 2.

It is noticed that the PV production is very poor in terms of a 75 kWp PV system, on the contrary the demand has large magnitude. It fluctuates with periodic peaks that is due to the heat pump running on the site day and night.

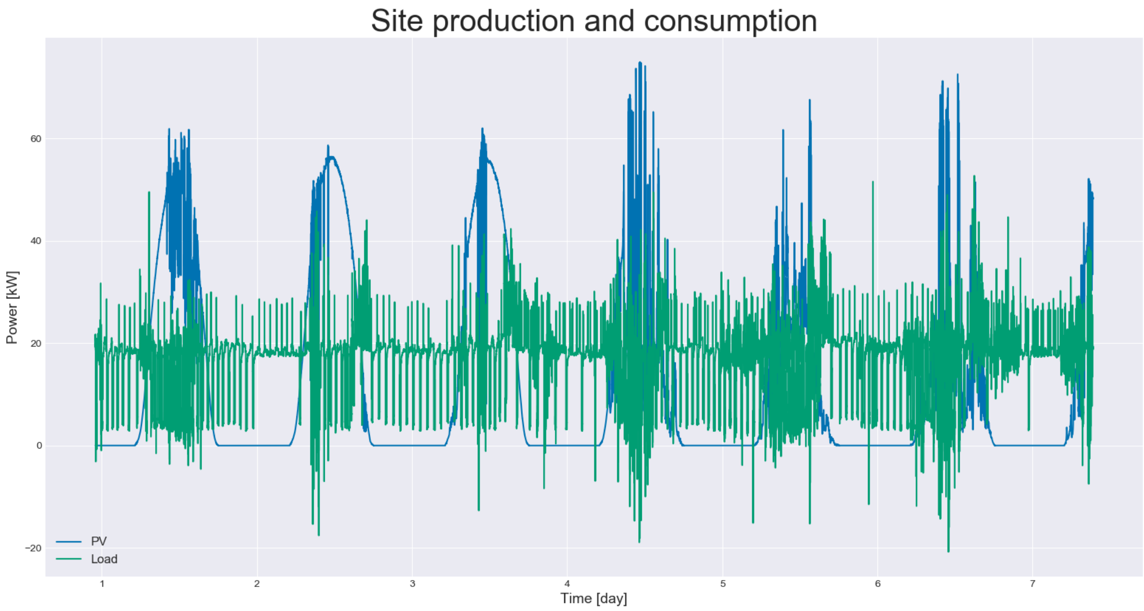


Figure 1. One-week observation on demand and PV production on site.

The voltage during this period has been plotted as histogram in Figure 2. This gives us a better understanding of the voltage on site. Based on the observation it shows that although the voltage varies in 17V difference and the median voltage is at around 233V, it is still under the safety operational limit of 230V±10% according to the grid code. This means that there is no need of voltage support in this grid.

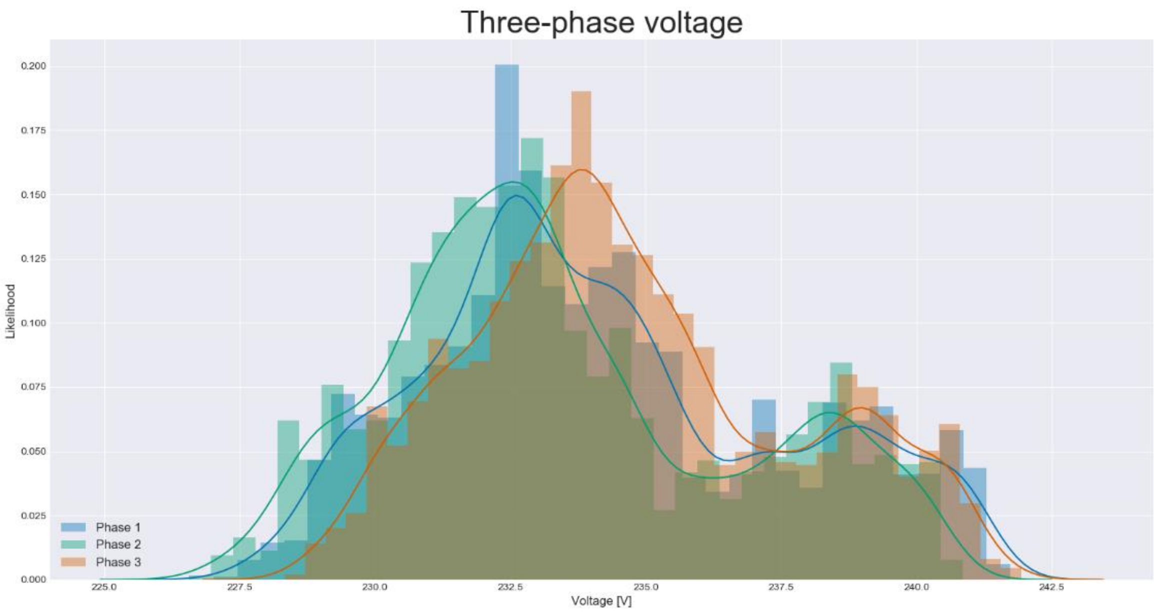


Figure 2. An overview of the voltage status in Spøttrup grid storage test site.

However, in order to prove the voltage support algorithm has been developed within the project is valid, we decided to design a more aggressive droop which can be applied to the current situation. The expected result should show the variance of the voltage distribution curve in Figure 2 is narrowed down and the amplitude of the distribution curve should be higher as well. The voltage distribution in Figure 2 will be used as baseline during the following test.

During the test, the voltage reference is set to be 231V. The three-phase voltage distribution in Figure 4 could be found has smaller variance compared to the baseline and the amplitude is noticeable higher which means the fluctuation of the voltage during the test period has been successfully regulated.

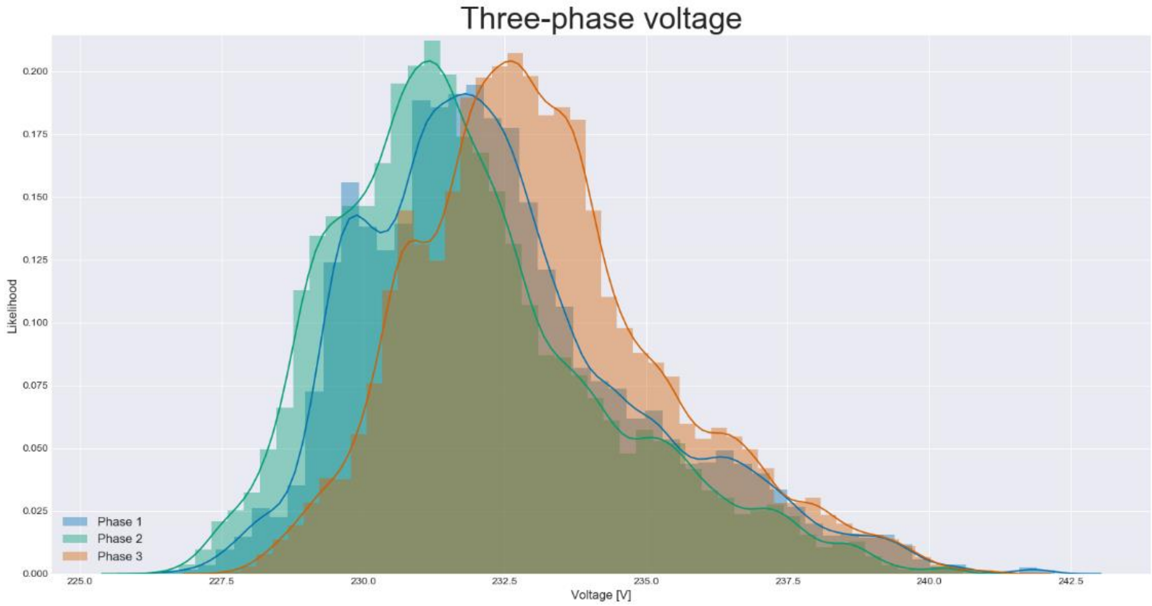


Figure 3. Three-phase voltage under voltage support mode operation.

A comparison on the average three phase voltage of the test result and baseline is shown in Figure 5. The median voltage has been moved from 233V to 231.3V, and the variance has changed from 9.76 to 5.48.

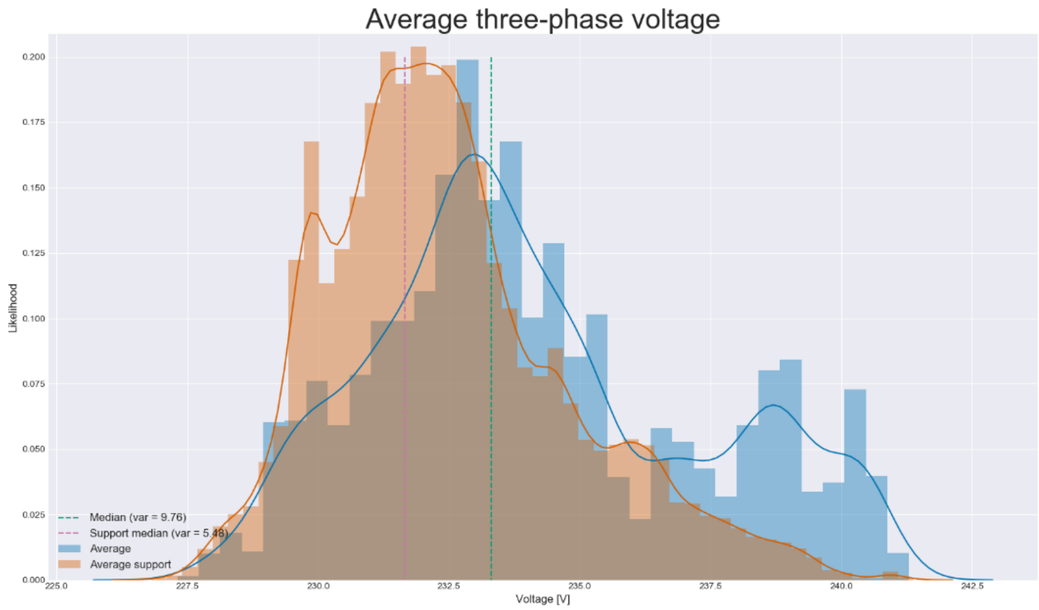


Figure 4. Average voltage of voltage support test result versus baseline average voltage.

As the ESS is running max self-consumption mode at the premises most of the time, we have also collected voltage data from max self-consumption mode operation. Since max self-consumption mode intend to store excess solar energy to use later in the evening, in theory this should also improve the voltage stability in the grid. Here the average voltage of max self-consumption mode is plotted together with voltage support mode and baseline in Figure 5.

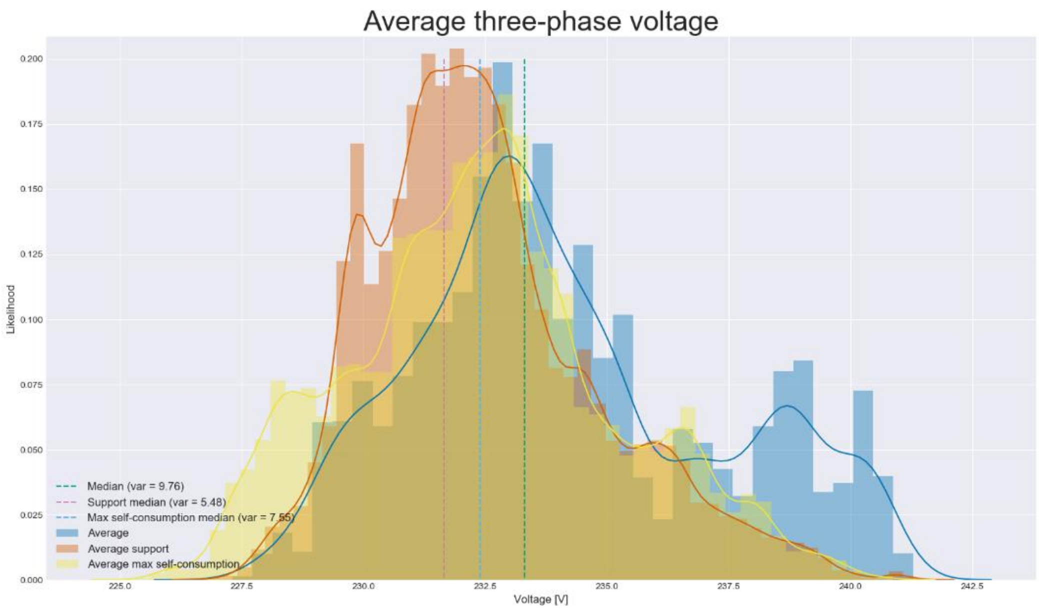


Figure 5. Average voltage of max self-consumption mode, voltage support mode and baseline.

As expected, the max self-consumption mode improved the voltage stability as the variance of the distribution is narrowed, the magnitude is higher compared to the baseline, however from the voltage control point of view, it doesn't work as efficient as the voltage support mode.

In voltage support mode, ESS acts as a load when the voltage is high and acts as a generator when voltage is low. It reacts on voltage changes rapidly, which forms a mirrored inverter power curve to the grid voltage as shown in Figure 6. By comparing Figure 6 with Figure 7, when the ESS reaches fully charged or discharged the inverter will stop providing voltage support, otherwise the request has been well handled.

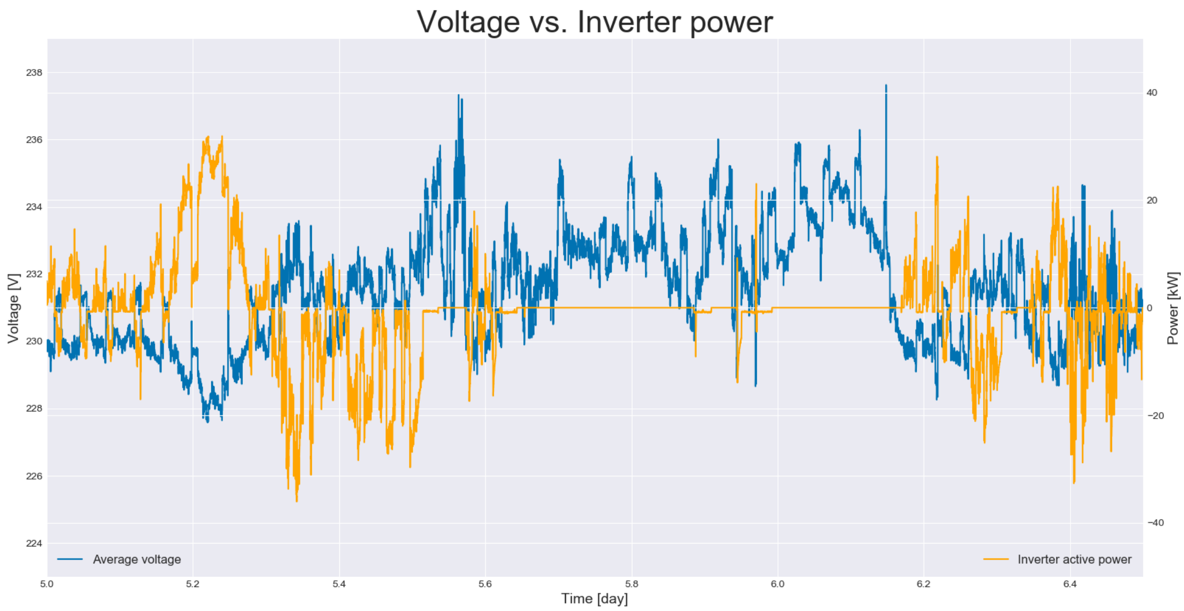


Figure 6. Inverter power versus grid voltage.

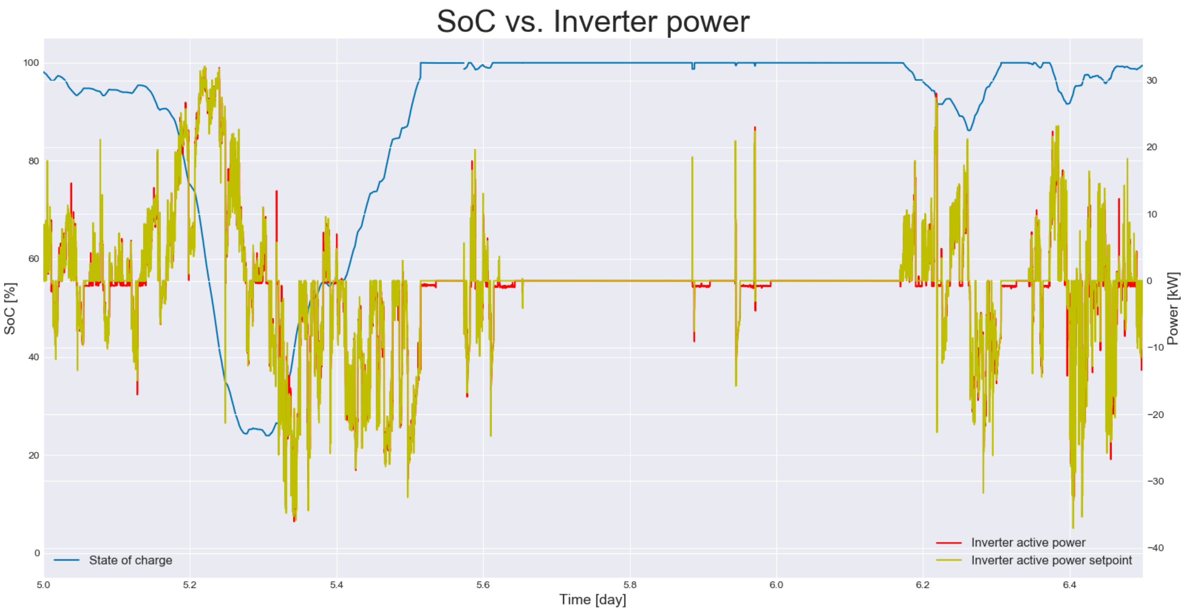


Figure 7. Inverter power versus ESS state of charge.

The conclusion of the test shows BESS can provide voltage support and it can help stabilize the grid to some extent. In order to have a fully functioned BESS, dimensioning is critical. A pre-study of the target grid situation and the end goal should be well analyzed when deciding the battery size, otherwise it will be either too expensive for the investor or the BESS cannot function as expected.

<u>Business opportunity for grid utility case</u>

As the project description has mentioned there are few solutions can help the excess PV power issue:

- Curtail the power output from the PV-plant – resulting in a loss for the PV-owner
- Generate reactive power instead of active power if there is a need in the grid – new reactive feed in tariff (FIT) has to be developed
- Consume the exceed energy that causes the voltage problems
- Upgrading the grid with thicker cables that can carry more load or installing new 10/0,4 kV transformers will lead to very high expenses and also risky investments since the penetration of local energy production is rapidly growing and very hard to predict, you can easily calculate grid reinforcements that will only last a short period before problems in quality will arise again
- Store the energy when it creates problems and consume when needed

The first 2 points currently cannot benefit the PV owners until new regulation settles. The last three points are more realistic solutions under current framework. In this project, the focus is also on the last three points, here we investigate how can battery relief grid congestion problem caused by high renewable penetration, so that can be a temporary or permanent solution to substitute conventional grid strengthening.
Grid strengthening cost on the 0.4 kV transformer side regarding increase of PV installation is very difficult to estimate since it is a case to case project. From the data provided by Eniig Holding A/S for grid strengthening in Fur, the per kWp price regarding enlarge PV installation on the 0.4 kV grid varies from 8292 DKK/kWp to 1118 DKK/kWp, this includes the cost of construction work and cables.

The battery system has delivered to Spøttrup is a 79 kWh/50kW system which cost 285000 DKK. The per kWh price is 3608 DKK/kWh, and from power perspective it costs 5700 DKK/kW.
It is not possible to make a comparison of these 2 solutions in cost, due to lack of information, however from the application point of view, it gives some differences. Grid strengthening by adding transformers and cables is a solid solution for long term regarding its stability and long lifetime, but the planning, dimensioning and construction takes long, therefore the project requires large timeframe. On the other hand, adding battery system as a grid facility is a lighter and shorter-term project compared to conventional grid strengthening. It requires less construction work and has more flexibility regarding the system capacity and location. However, the drawback of the battery system is also very outstanding, which is the lifetime. Based on our current experience, there are few business scenarios maybe interesting of using battery instead of conventional grid strengthening.
Rapid increase of PV installation
Battery system has clear advantage in its scalability and short commissioning time in case of rapid changes in the grid. This applies to both increasing of renewable generation and extra load such as EVs. Less planning and construction time makes the congestion problem in the grid can be solved timely. The flexibility of the rack-structure makes battery easy to scale up or down regarding system capacity and power to fit the need.

<u>Temporary solution before grid strengthening</u>
As the grid strengthening project is normally long and heavy, add a temporary battery system into the grid during the project period can help mitigate the grid problem. It also can be a backup solution in case of black out caused by the construction work. A battery system company as Lithium Balance may consider provide such services such as battery rental business for utility companies. This may also be an opportunity to boost the market of second life battery.

<u>Power smoothening</u>
We have experienced that renewable generations are not stable due to weather. The spikes in the power profile leads to voltage fluctuation in the grid. Besides spikes, peak renewable generation from a large plant also cause voltage problem. As voltage issue always stays locally, it would be helpfully to have battery installed at the site and perform power smoothening before the voltage problem occurs. However, under the current regulation, site owner cannot receive any tariff on this application. This requires further development on the FIT (feed-in tariff).

<u>Li-on battery price</u>

With increasing demand of lithium battery, manufacturers enlarge the production line as shown in Figure 8 and battery pack prices have fallen by an average annual rate of 21% since 2010, or at an 18% learning rate with every doubling in production as shown in Figure 9. It is foreseen that the capital cost for new planned manufacturing capacity (on a per-gigawatt hour [GWh] basis) to drop by more than half from 2018 to 2023 (Bloch, Newcomb, Shiledar, & Tyson, 2019).

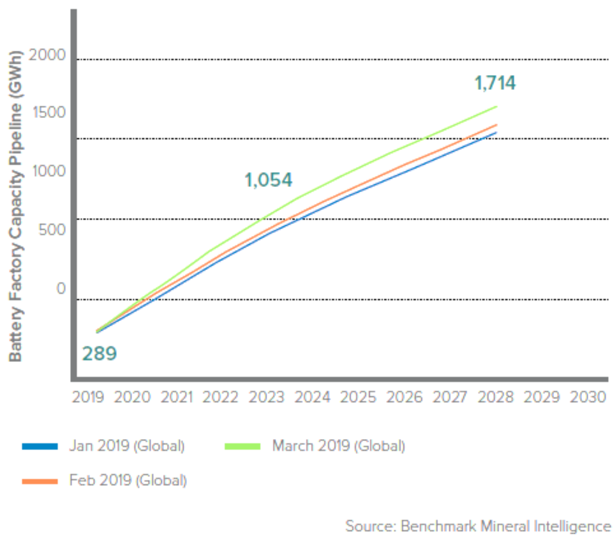


Figure 8. 2019 Q1 Growth in Global Battery Factory Capacity Pipeline (GWh) [1]

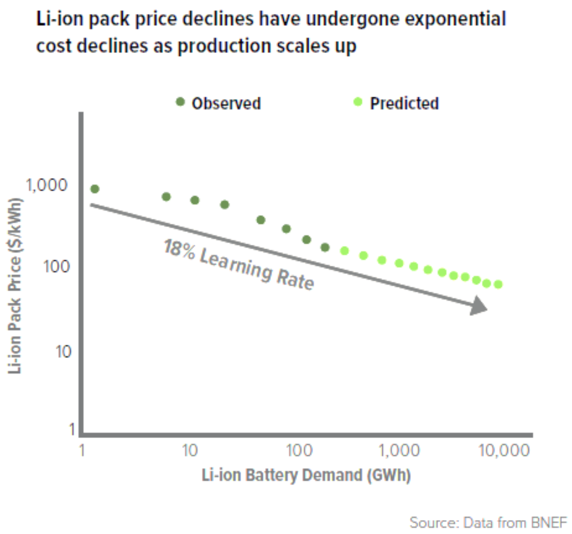


Figure 9. Historic and Projected Li-ion Pack Price Declines against Production (Bloch, Newcomb, Shiledar, & Tyson, 2019)

The current market price for a complete battery system (including commissioning) is in the range of 3500 – 4000 DKK/kWh. This means with the declining in battery pack price, battery system will be a more affordable option for grid utilities in the near future.

7.4 Commercial results.

The project has been in contact with several energy distribution companies, discussing the possibilities to add battery storages as and temporary solution to overloaded distribution transformers. Thereby deferring costly transformer upgrades to the point where the grid radial is clear or just to defer the investment itself. Lithium Balance expect to have a few (around 5) of these systems installed in 2021, mostly to demonstrate the feasibility to DSO's, and hopefully get their general acceptance of the concept. Which then could lead a good business by 2021-2023, since there are 1000's of these transformers in the grid, and as more energy demanding/consuming items are transferred from fossil fuels to the electric grid the potential will grow. The algorithms used for in this project could with relatively small modifications be used for this, the main adaptation would be mechanically to fit DSO needs

The potential of the DC-DC coupled battery system is large, since 100.000 PV systems already exist in Denmark alone, only a fraction of these have battery storage today and many would benefit to have this. But quite a bit of further R&D would be needed to take these prototypes to a level where it can be used by consumers on their household PV systems. But then again, the possible market is very large. The project has given a great inside and platform to start from and therefore reduced the risks involved in the product maturation process.

Expectations of the project from Lithium Balance:

- We are convinced that placing a battery storage at the last grid radial transformer have great business potential, but I will take some time to get there. We expect that we could sell 20-50 systems a year when DSO's have accepted the concept giving a potential turnover of up to 10 mio.kr/yearly and additionally 5 employees as a result in Denmark alone. Other countries are potential markets doubling many times over the possible number of units that could be sold. The acceptance of Danish DSO is critical for this to happen since references are a key selling point.
- The DC-DC based battery system also has great potential, but R&D is needed and competing solutions are also emerging, making a clear-cut case for further development, more marked research is needed.

Dissemination of the project:

- The grid support function has been demonstrated to several DSO and some has shown a serious interest
- The Spøttrup system was featured on TV2 news in November 2019, see link in the annex.

8. Utilization of project results

Lithium Balance expect to get a significant revenue increase from battery systems installed in conjunction to grid strengthening as described above.

Lithium Balance will target DSO's, primally in Denmark as a start and they hope to have a few systems in 2021 and a broader acceptance in 2022 and forward. This area has become an important part of their business plans and may end contributing with 5-10% of their total revenue. Now we do not see others approaching this marked giving Lithium Balance a unique position but also more works since we have to establish the marked.

Overall, the energy storage grid voltage support use case shows, that the potential of a decentralized battery can improve the grid power quality. Potentially reducing the needs for grid strengthening and indirectly reducing the overall costs for the green transition.

On the DC-DC connected battery system Lithium Balance do believe that they have found some unique technical solutions which are being patented investigated which looks promising. But the overall business case needs to be investigated further before further investments are being made.

9. Project conclusion and perspective

The Local Energy Storage project has finished in line with the budget. Very promising technology has been developed that will be unique and attractive in the market for residential BESS for PV installations. It holds the promise of becoming a very cost attractive BESS solution, both for new PV installations and retrofit of existing PV installations. Provided that the real-life demonstration shows as good results as expected after the prototype tests in lab. The development will continue based on the current result; it is expected that the solution can be launched commercially in 2021.

Lithium Balance has continuously during the period discussed and presented the BESS solutions to potential partners and customers to get their feedback in order to prepare for commercial launch when the products are ready. The interest is very high and positive.

10. Annex

"Lokal hal har fået et kæmpe batteri"
https://www.skivefolkeblad.dk/artikel/verdens-forste-af-sin-slags-lokal-hal-har-faet-et-kaempe-batteri

C. Bloch, J. Newcomb, S. Shiledar e M. Tyson, «Breakthrough Batteries: Powering the Era of Clean Electrification,» Rocky Mountain Institute, 2019.