Final report

1.1 Project details

Project title	Advanced Components for Electro Mobility Usage
Project identification (program abbrev. and file)	ACEMU
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Lithium Balance A/S Hassellunden 13, 2765 Smørum
Project partners	Banke Accessory Drives Meldgaard Miljø Aalborg Universitet
CVR (central business register)	29391130
Date for submission	30-09-2018

1.2 Short description of project objective and results

This project wants to address a large potential market by developing new power electronic systems for large scale lithium-sulfur batteries, focusing on the market for electromobility. Electric cars are still too expensive compared to vehicle driven by fossil fuels. The batteries are to a high extent responsible for the high price for electric vehicles. In addition, the consumers hesitate to invest in electric car technology due to safety concerns related to lithium-ion batteries (Li-ion) and because of the relatively short range per charge of electric vehicles – at project start typically 150 km per charge. The consortium intends to address the weight and space constraints by conducting research into lithium-sulfur batteries (Li-S), that has 5 times higher theoretical energy density than traditional Li-ion batteries. Li-S cells are also very safe. The consortium will also conduct research and development in embedded power electronic systems with the purpose of reducing cost, size and weight. The objective is, that Li-S cells together with the developed BMS is implemented successfully in the demonstration phase of the project in a work-vehicle and that the associated business cases will address the viability of the products and technology in various markets.

Dette projekt ønsker at adressere et stort potentielt marked ved at udvikle nye effektelektroniske systemer til storskala lithium-svovl-batterier, der direkte er rettet mod markedet for elektromobilitet. Elbiler er stadig for dyre sammenlignet med køretøjer med fossile brændstoffer. Batterierne er i høj grad ansvarlig for den høje pris på elbiler. Derudover er forbrugerne tilbageholdende med at investere i elbils teknologi på grund af sikkerhedsmæssige bekymringer med hensyn til lithium-ion (Li-ion) batterier og på grund af den begrænsede rækkevidde af elbiler – ved projektets start typisk 150 km per opladning. Konsortiet ønsker at tage fat på plads og vægt begrænsning ved at gennemføre forskning i Lithium Svovl batterier (Li-S), som har op til 5 gange højere teoretisk specifik energi end traditionelle lithium-ion batterier. Li-S-celler er desuden kendetegnet ved at være meget sikre. Konsortiet vil også forske i indlejrede effektelektroniske systemer med henblik på at reducere omkostningerne, størrelse og vægt. Målet er, at Li-S-celler med den udviklede BMS kan påvises i demonstrationsfasen af projektet på et arbejdskøretøj og man gennem de tilknyttede business cases for en perspektivering af enheden og teknologien i forhold til de forskellige interessenters markeder.

1.3 Executive summary

- The research in lithium sulfur (Li-S) batteries in this project has shown that there is still some way to go before Li-S can be used in commercial products. The challenge of Li-S in an e-mobility context is that the charging process takes a long time (about 10 hours), the capacity is reduced at high currents and effects, the service life is still too short (approximately 400 cycles), and there is a relatively high self-discharge at state-of-charge greater than 70%.
- The BMS developed in the project has been well received by Lithium Balance's customers. The BMS has been marketed during 2017, and more than 25 customers are testing the solution - primarily electric car manufacturers, including five of the top ten car manufacturers worldwide. At the end of the project, two of these customers have decided to use the BMS platform in concrete electric vehicle development projects after thorough testing.
- The hot-swapping battery pack developed in the project is already in place at several of Banke Accessory Drives' customers. The hot-swapping concept makes it easy to service the battery pack. At some selected customers, the concept is further tested to assess whether it is practically possible and safe to ensure that the customers conduct hot swapping cell exchange on their

own and without on-site support from Banke. The conclusion is positive and results in significant lower service costs for Banke and faster problem resolution for the customer. The developed concept is now used as a starting point for all new product developments.

- Li-S batteries have been characterized and tested. Electric models have been developed to model the dynamic voltage response as well as the self-discharge. Li-S batteries have a relatively high self-discharge when state-of-charge is greater than 70%, which can be utilized as passive balancing. A lifetime assessment procedure has been developed. Likewise, methods of estimating the state of the Li-S batteries state-of-charge and state-of-health.
- It has been demonstrated that an engine controller can also be used for charging if the battery voltage is above a critical level. However, a method has been developed that allows for a less critical battery voltage. The engine windings have also been used as a net filter, which reduces costs. For practical reasons, however, it is inappropriate to use the engine as part of the filter.
- A multilevel converter has been built that can both function as a motor controller and battery charger, while also balancing the energy battery modules in between. The overall functions have been demonstrated in the laboratory.

1.4 Project objectives

The battery technology used in the project is Lithium-sulphur (Li-S) batteries from the British battery manufacturer Oxis Energy. Systems using metallic lithium are known to offer the highest specific energy and coupled with sulphur they have an extremely high theoretical specific energy, which is 5 times higher than that of Lithium Ion. 350 Wh/kg has already been demonstrated. So, for the same energy stored, the battery will be significantly lighter – or for the same size battery, the driving range will be significantly longer.

Inherent in the Li-S cells from Oxis Energy are two key mechanisms which protect the cells: a ceramic lithium sulphide passivation layer and a non-flammable electrolyte. This means that the cell can survive a barrage of electrical and physical abuse, including puncture, without any adverse reaction. These cells also have a 100% available Depth-of-Discharge and cannot be damaged by over-discharge. These features make the Li-S cells much safer than current Li-ion batteries and this addresses the other main concern for the adoption of electric vehicles.

Li-S batteries still need a BMS to optimise the performance of the battery pack and ensure its safety and operational life as cell life will be reduced when overcharged. With Li-S batteries the current main limitation is the cycle life. At project start Oxis expected to increase cycle life from 400 to 900 charge/discharge cycles by 2015, and a major contributor for this improvement is the charge/discharge control managed by the BMS. The BMS also needs to consider that the nominal voltage per cell is only 2.1 V compared to 3.2 V - 3.7 V for different Li-ion chemistries. Finally, the discharge curve shows a slight increase in voltage in the "plateau" region of compared to other lithium technologies, and this puts a special challenge on the state-of-charge algorithms. The battery research in the ACEMU project studied these effects in Li-S batteries and the resulting data was used to develop dedicated Li-S control algorithms that were implemented in the BMS in the demonstration stage of the project in order to provide extended cycle life, and accurate SoC and SoH estimations.

At project start Li-S batteries were still an object of research and not commercially available for electromobility applications. Oxis Energy was however able to provide first smaller test cells (2-3 Ah) for the research activities in this project and later on also larger cells for a battery pack demonstrator (at least 20 Ah per cell). The goal was that the Li-S cells with the developed BMS should be demonstrated in the demonstration phase of the project to have the following performance characteristics:

• Specific energy 250 Wh/kg

• Volumetric energy 300 Wh/l

• Discharge rate: 3C

• Charge rate: 0,25C

• Cycle life: 900 cycles at 80% DoD

• Temperature range: -20C to +80C

An illustration of the impact of this battery technology on the driving range of an electric vehicle could be typical trucks used for distribution of goods in Denmark. At the sides of a truck chassis there is plenty of space for a battery, but the battery weight impacts the total weight of the truck, and thus results in a smaller allowed payload of transported goods.

In the Netherlands MAN has for example implemented several electric trucks a few years ago based on their 15 tonnes truck chassis. The batteries used are LFP cells (100 Wh/kg and 130 Wh/L) and with an 80-kWh battery pack the payload is about 7 tonnes – the same as in the conventional diesel version. However, the driving range per charge is only 80 km. The largest battery option is a 240-kWh battery pack that results in a 240 km range, but payload is reduced to 4,5 tonnes. With Li-S batteries it would be possible to install a 190-200 kWh battery without reducing payload and increase driving range per charge from 80 to approximately 200 km. Further weight reductions can be achieved by combining the different power electronic systems into on unit as developed in this project, and this allows an even larger battery pack to be installed without affecting payload, and thus increasing range beyond 200 km/charge.

In the ACEMU project the developed solutions were to be implemented in a vehicle from Meldgaard and used as the demonstrator. The Li-S research however revealed that Li-S was not ready for use in large trucks, so while other components were demonstrated in the Meldgaard truck, the Li-S batteries and a BMS with the developed algorithms were demonstrated in a smaller electric scooter.

1.5 Project results and dissemination of results

- The starting point at the start of the grant period - the initial goals and assumptions.

  Lithium Sulfur (Li-S) Batteries: Li-S was and is still on the verge of becoming commercially available. The purpose of conducting research into Li-S batteries was therefore to understand how:
  - battery characteristics, e.g. Available capacity and power depends on the environment, for example. temperature, charging mode, current, etc.
  - The same parameters affect the battery life

- The battery fits into an e-mobility context

Embedded power electronics systems: By utilizing power electronics in a smarter manner, the same hardware can fill in more features, such as motor control, charger, and battery management system. The purpose of this research was therefore to investigate how
  - Components can be avoided by better utilizing the existing hardware
  - Batteries can be directly integrated into power electronics
  - Power electronics are used for cell balancing

- Significant changes during the grant period.

  The biggest change in the project was probably the decision to NOT to demonstrate lithium-sulfur batteries in a garbage truck. The reason for this decision was that the Li-S batteries did not have the maturity level required to be used in such an application, since
  - Capacity is greatly reduced by high current discharging, as in a garbage truck. Therefore, it will be necessary to oversize the battery, but the energy / weight ratio will therefore be too low relative to the alternatives.
  - The charging time of 10-11 hours is too long for a garbage truck application, where some customers collect garbage several times a day.
  - Lifetime (both cyclic and calendar) is still too short.

  Instead, it was chosen to demonstrate the batteries on an electric scooter application. See picture below.

Figure 1: Electric-scooter used for demonstration of Li-S batteries.

- Important results

  Lithium-sulphur (Li-S) batteries
  A very good understanding of how the capacity and life span depends on the temperature and power level, as well as how many recharges and discharges the battery can handle. The battery has a relatively poor service life (<400 cy-

cles) and high self-discharge. However, the high self-discharge can be utilized as passive cell balancing, which simplifies the battery management system. The batteries we got from the manufacturer were handmade prototypes. Unfortunately, the results from these batteries showed that technology is not yet mature enough to replace traditional battery solutions.

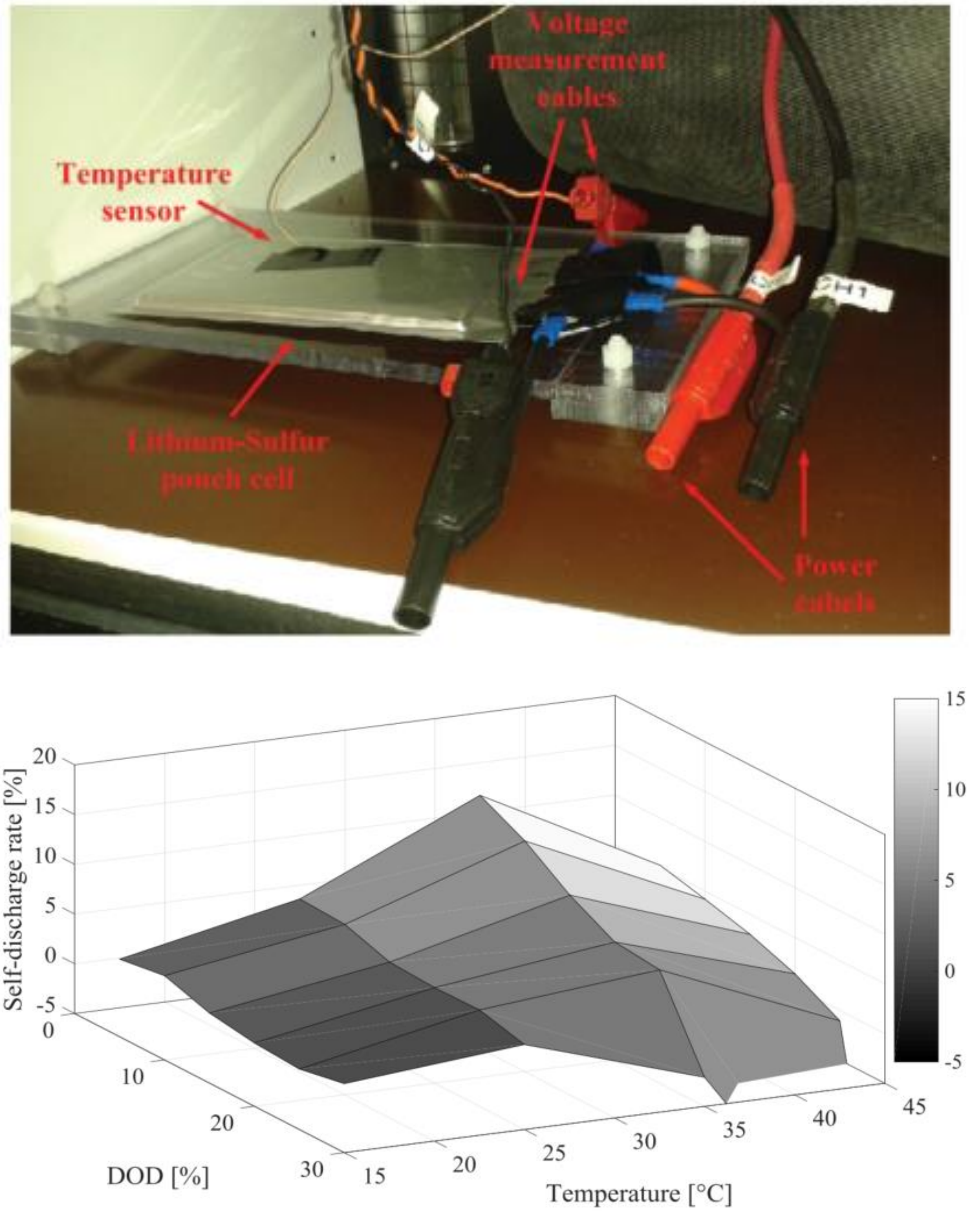

Figure 2: Top: Picture of a Li-S cell under test. Bottom: Self discharge as a function of temperature of depth-of-discharge.

Embedded power electronic systems
It has been demonstrated in the laboratory that it is also possible to use the motor controller to charge the battery pack. This has also been demonstrated by using the motor windings as a net filter. A dedicated network filter can therefore be avoided or reduced. See the figure below. However, this solution is limited by the fact that the battery voltage must not be below a critical level, otherwise the power cannot be controlled during charging. However, in this project, a method has been developed to accept an even lower critical voltage. The use of engine windings as a part of a network filter has proven to have its practical constraints on three-phase charging, as it is necessary to have access to the star's point in the engine, which is rarely possible. But for single or two-phase

charging, it is still practically possible, but charging time will last longer. The use of the motor controller as a charger does however mean that there is no galvanic separation between the net and the battery pack, which in some cases is desirable.

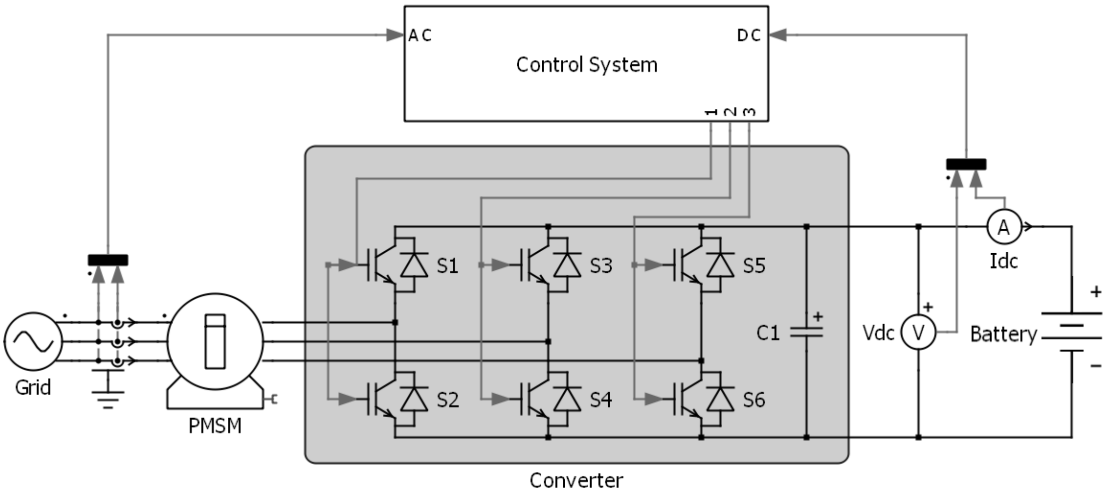

Figure 3: Converter (motor controller) used as a battery charger with the motor windings utilized as grid filter.

Another important element in the research on embedded power electronics systems is the construction of a multilevel converter in the laboratory. See picture below.

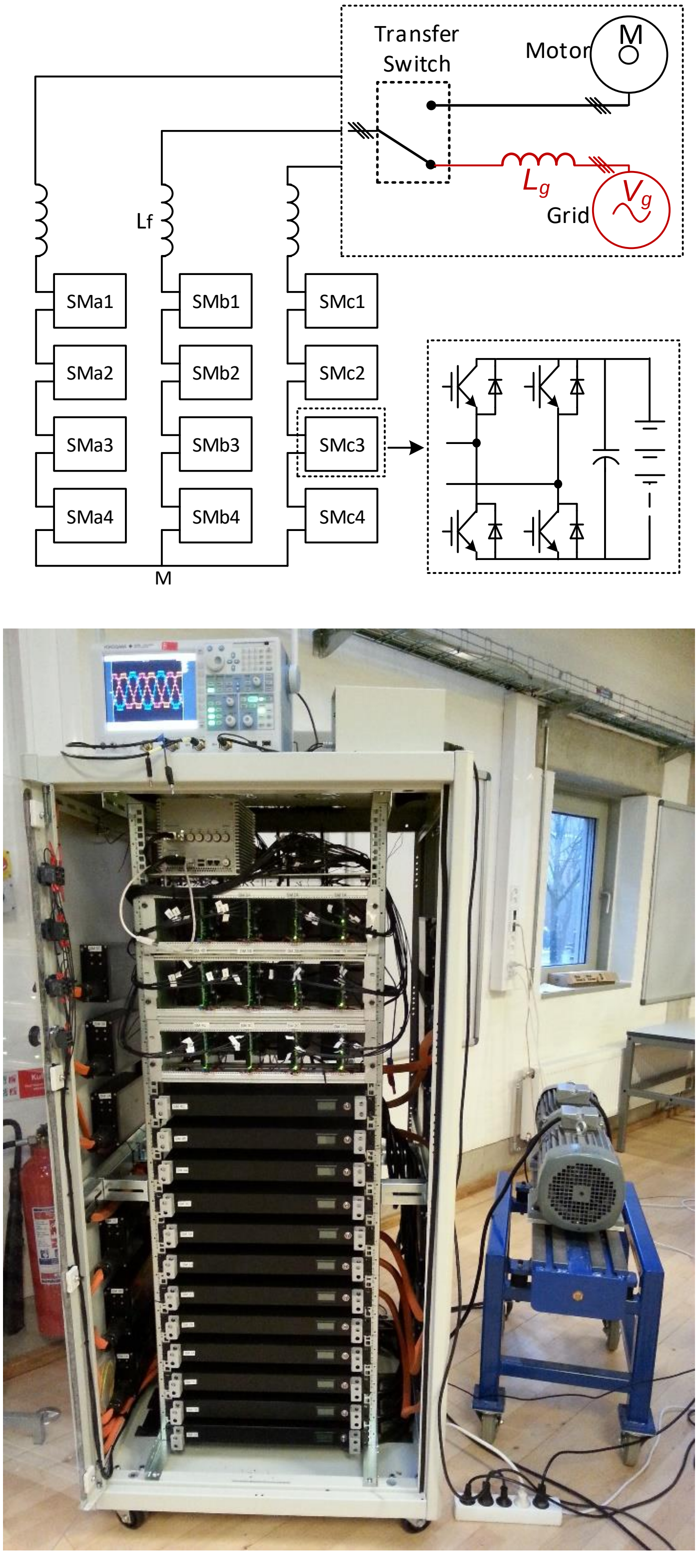

Figure 4: Multilevel converter with integrated battery modules. Top: System diagram. Bottom: Laboratory system.

Like the previous system, the multilevel converter can also be used as engine controller and charger. However, the multilevel converter can also balance the energy between the different battery modules, which has the benefit that, when replacing battery modules, the balancing occurs very quickly as opposed to traditional battery management systems. See figure below for demonstration of cell balance during charging.

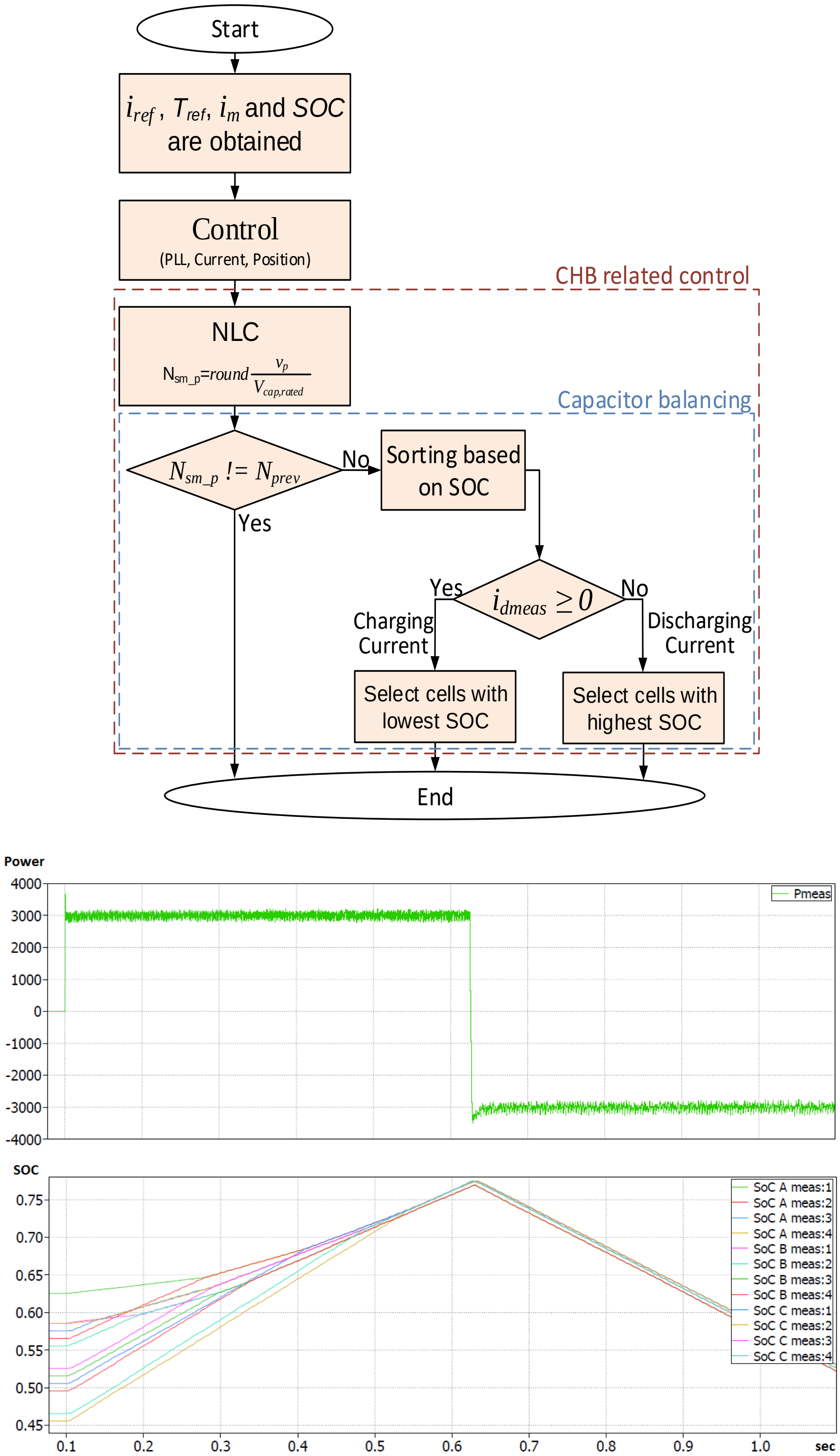

Figure 5: Multilevel converter. Top: Balancing strategy. Top: Demonstration of balancing during charge.

- Important tasks and challenges

  To be able to balance at cell level instead of only at module level is a natural next step in development of the earlier mentioned multilevel converter. This work was also started in the ACEMU project, where printed-circuit-boards have been developed. See figure below. Research grants have been applied for at Danmarks Frie Forskningsfond.

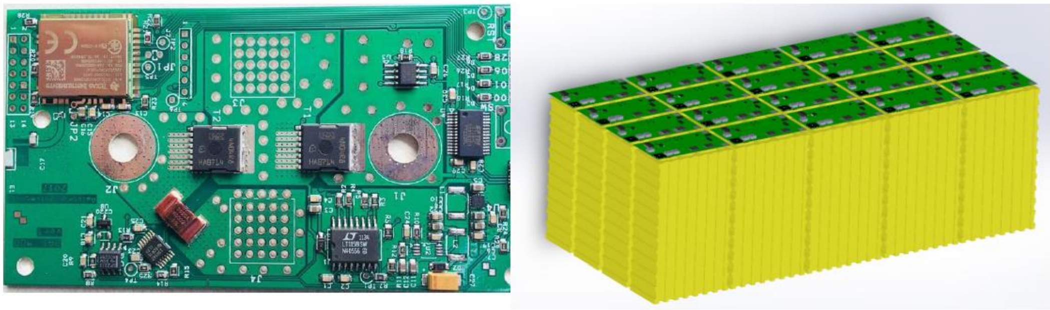

Figure 6: Multilevel converter at cell level. Left: Printed-Circuit-Board. Right: complete battery pack with cell level multilevel converters.

- Commercial expectations

  As it has already been described, lithium-sulphur battery technology is not yet mature enough for commercial exploitation. Banke Accessory Drives will therefore continue to base their battery packs on traditional Lithium Iron Phosphate battery cells.

  Banke Accessory Drives has however in the ACEMU project successfully developed a Hot-swapping battery pack which is already being used by customers.

  The ability to hot swap battery modules in a battery pack makes it easier to do service on the pack, because it is possible to access every single battery cell and if necessary exchange it. This has been made relatively easy in a 192 cell battery pack. In addition, this operation can be performed safely in the field, and often without dismounting the battery pack from the vehicle. In total this reduces the service cost in case of the need for cell exchange considerably. The cell exchange can be performed in typically 3-4 hours, compared to the alternative of taking off the entire battery pack from the vehicle, send it to Banke or another service provider, where the pack is disassembled, cells exchanged, pack reassembled, shipped back and reinstalled on the vehicle. A process that would be many times more time-consuming and costlier, which also leaves the vehicle non-operational in the meantime. Comparing this to the cost and time saving of hot swapping, and not the least better customer satisfaction when experiencing a problem being solved at once in one operation avoiding many practical and logistical problems. This concept is unique in the market currently.

  Other optimizations because of the hot swapping concept are related to the BMS system. For example, if the BMS is able to balance a replaced cell so it matches the other cells in the pack. Or if the BMS provides the service technician with statistics about the status of all cells in the pack, so that it is easy to identify all weak cells and replace them at the same time. The additional time needed to replace 2 cells instead of one is less than an hour.

Figure 7: Battery pack for garbage truck with hot swap battery modules developed by Banke. Left side: BMS from Lithium Balance installed on the battery pack, Right side: battery modules that are hot swap enabled.

For Lithium Balance the ACEMU-project has contributed to developing its n-BMS platform, which has been released in the project period and at the end of the project it has been sold to more than 25 customers in the automotive industry.

Figure 8: Automotive grade n-BMS platform developed by Lithium Balance

Besides the commercial dissemination activities (see 1.6) the research results have been disseminated via 21 scientific articles, 3 student projects, one PhD dissertation and 2 workshops.

1.6 Utilization of project results

Lithium Balance started presenting the new n-BMS platform to new customers beginning of 2017. This was and is still done at exhibitions, conferences, advertisements and articles in trade journals. The automotive industry has received the new product with high interest and at the project completion more than 25 automotive customers are testing the platform. The company has also updated its business plan based on the results of the ACEMU project, and as a result of this work raised new capital from an industrial automotive investor. This capital injection will be used to further develop the BMS platform, but also to lift the competence of the organization with more test facilities, quality certifications and additions to the sales organization to become a qualified automotive supplier. In connection with the activity 10 more employees have been added the previous six months, corresponding to a 50% increase.

Banke has also seen a dramatic improvement in sales with the new hot swap platform from 2017 to 2018, which they expect to maintain or expand in 2019.

The project has not resulted in new patent applications but is based on existing patent at Lithium Balance.

The project results contribute to the transition from fossil fuelled transportation to electrification and thereby the potential to reduce CO2 emissions.

A PhD student has been an essential part of the ACEMU-project, and his research has led to key decisions in the project. He was also able to work closely with Cranfield University, who has special competencies in Lithium-Sulphur batteries, during the project. His work has resulted in several scientific articles and he is now employed in another battery related research project at Aalborg University.

1.7 Project conclusion and perspective

The partners consider the results of the ACEMU project highly successful

For AAU the project made it possible to do research in the areas of:

- A new battery technology, Li-S batteries
- Integration of power electronics and batteries

For Lithium Balance the project facilitated:

- Close collaboration with the Li-S cell manufacturer Oxis Energy and ensure that our BMS platform can be used with the Li-S technology, as soon as it becomes commercially available.
- The development of the n-BMS platform
- getting huge amounts of priceless inputs and test evaluations from a potential customer and user of the new BMS platform, Banke Accessory Drives, and from a knowledge institute with very high battery knowhow, Aalborg University.

For Banke Accessory Drives the ACEMU project has facilitated:

- the development of the hot swapping concept
- a relevant and valuable cooperation with Aalborg University, which is now also utilized outside of the project.
- Development of a systematic and well documented training program for customers and service partners.

The ACEMU project was as one of the first teams in the World get access to the new Lithium-Sulfur battery technology for cell testing and integration into a battery pack, and implementation in a scooter for performance testing. The project has developed unique knowledge about the management of such cells to possibly increase their performance. The Li-S technology has high potential for solving some of the main limitations of Li-ion in terms of lower weight and higher safety, but the project also revealed that this technology still needs to develop further before it can replace Li-ion technologies in many electric applications.

Annex

Scientific production and dissemination

Journal Articles

1. Reference Performance Test Methodology for Degradation Assessment of Lithium-Sulfur Batteries. / Knap, Vaclav; Stroe, Daniel Loan; Purkayastha, Rajlakshmi; Walus, Sylwia; Auger, Daniel J.; Fotouhi, Abbas; Propp, Karsten. Submitted i: Electrochemical Society. Journal, 2018. To be submitted
2. Concurrent Real-Time Estimation of State of Health and Maximum Available Power in Lithium-Sulfur Batteries. / Knap, Vaclav; Auger, Daniel J.; Propp, Karsten; Fotouhi, Abbas. Submitted i: Energy Storage. Journal, 2018. To be submitted
3. Methodology for Assessing the Lithium-Sulfur Battery Degradation for Practical Applications. / Knap, Vaclav; Stroe, Daniel-Ioan; Purkayastha, Rajlakshmi; Walus, Sylwia; Auger, Daniel J.; Fotouhi, Abbas; Propp, Karsten. I: ECS Transactions, Bind 77, Nr. 11, 2017, s. 479-490.
4. Thermal Behavior and Heat Generation Modeling of Lithium Sulfur Batteries. / Stroe, Daniel-Ioan; Knap, Vaclav; Swierczynski, Maciej Jozef; Schaltz, Erik. I: ECS Transactions, Bind 77, Nr. 11, 2017, s. 467-476.
5. Transferring the Incremental Capacity Analysis to Lithium-Sulfur Batteries. / Knap, Vaclav; Kalogiannis, Theodoros; Purkayastha, Rajlakshmi; Beczkowski, Szymon; Stroe, Daniel-Ioan; Schaltz, Erik; Teodorescu, Remus. I: ECS Transactions, Bind 77, Nr. 11, 2017, s. 1919-1927.
6. An Electrochemical Impedance Spectroscopy Study on a Lithium Sulfur Pouch Cell. / Stroe, Daniel Loan; Knap, Vaclav; Swierczynski, Maciej Jozef; Stanciu, Tiberiu; Schaltz, Erik; Teodorescu, Remus. I: ECS Transactions, Bind 72, Nr. 12, 10.2016, s. 13-22.
7. A self-discharge model of Lithium-Sulfur batteries based on direct shuttle current measurement. / Knap, Vaclav; Stroe, Daniel Loan; Swierczynski, Maciej Jozef; Purkayastha, Rajlakshmi; Propp, Karsten; Teodorescu, Remus; Schaltz, Erik. I: Journal of Power Sources, Bind 336, 12.2016, s. 325-331.
8. Investigation of the Self-Discharge Behavior of Lithium-Sulfur Batteries. / Knap, Vaclav; Stroe, Daniel Loan; Swierczynski, Maciej Jozef; Teodorescu, Remus; Schaltz, Erik. I: Electrochemical Society. Journal, Bind 163, Nr. 6, 03.2016, s. A911-A916.
9. Significance of the Capacity Recovery Effect in Pouch Lithium-Sulfur Battery Cells. / Knap, Vaclav; Zhang, Teng; Stroe, Daniel Loan; Schaltz, Erik; Teodorescu, Remus; Propp, Karsten. I: ECS Transactions, Bind 74, Nr. 1, 12.2016, s. 95-100.

Conference articles

1. Application Layer Design for Smart Battery Pack Control with Wi-Fi Feedback. / Lafrenz, Jan-Ludwig; Scheff, Phillip; Ricco, Mattia; Kerekes, Tamas; Olsen, Rasmus Loevenstein; Teodorescu, Remus; Liserre, Marco. Proceedings of 2018 IEEE Energy Conversion Congress and Exposition (ECCE). IEEE, 2018. Submitted
2. Highly Efficient Smart Battery Pack for EV Drivetrains. / Majmunovic, Branko; Sarda, Radhika; Teodorescu, Remus; Lascu, Cristian; Ricco, Mattia. Proceedings of 2017 IEEE Vehicle Power and Propulsion Conference (VPPC). IEEE, 2017.
3. Electric Circuit Modeling of Lithium-Sulfur Batteries during Discharging State. / Stroe, Daniel-Ioan; Knap, Vaclav; Swierczynski, Maciej Jozef; Schaltz, Erik, Proceedings of 2017 IEEE Energy Conversion Congress and Exposition (ECCE). IEEE, 2017. s. 1024-1029.
4. Functional Assessment of Battery Management System Tested on Hardware-in-the-Loop Simulator. / Kalogiannis, Theodoros; Stroe, Daniel-Ioan; Swierczynski, Maciej Jozef; Schaltz, Erik; Elkjær Christensen, Andreas. Proceedings of 2017 International Conference on Electrical and Information Technologies (ICEIT). IEEE Press, 2017.
5. State of charge balancing after hot swap for cascaded H-bridge multilevel converters. / Mathe, Laszlo; Schaltz, Erik; Teodorescu, Remus. Proceedings of the 2017 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) & 2017 Intl Aegean Conference on Electrical Machines and Power Electronics (ACEMP). IEEE Press, 2017. s. 741-746 7975057.
6. Battery pack state of charge balancing algorithm for cascaded H-Bridge multilevel converters. / Máthé, Lászlo; Burlacu, Paul Dan; Schaltz, Erik; Teodorescu, Remus. Proceedings of IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), 2016. IEEE Press, 2016.

7. Comparison of Parametrization Techniques for an Electrical Circuit Model of Lithium-Sulfur Batteries. / Knap, Vaclav; Stroe, Daniel Loan; Teodorescu, Remus; Swierczynski, Maciej Jozef; Stanciu, Tiberiu. Proceedings of the 2015 IEEE 13th International Conference on Industrial Informatics (INDIN). Cambridge, United Kingdom : IEEE Press, 2015. s. 1278-1283.
8. Electrical circuit models for performance modeling of Lithium-Sulfur batteries. / Knap, Vaclav; Stroe, Daniel Ioan; Teodorescu, Remus; Swierczynski, Maciej Jozef; Stanciu, Tiberiu. Proceedings of the 2015 IEEE Energy Conversion Congress and Exposition (ECCE). Montreal, QC, Canada : IEEE Press, 2015. s. 1375-1381.
9. Study on Self-discharge Behavior of Lithium-Sulfur Batteries / Knap, Vaclav; Stroe, Daniel Loan; Swierczynski, Maciej Jozef; Teodorescu, Remus; Schaltz, Erik, I: E C S Transactions, Vol. 70, Nr. 1, 2015, s. 95-103
10. State of Charge Balancing Control of a Multi-Functional Battery Energy Storage System Based on a 11-Level Cascaded Multilevel PWM Converter / Wang, Songcen; Teodorescu, Remus; Máthé, Lászlo; Schaltz, Erik; Burlacu, Paul Dan. Proceedings of OPTIM 2015. IEEE Press, 2015.
11. Electric vehicle battery charging algorithm using PMSM windings and an inverter as an active rectifier / Zaja, Mario; Oprea, Matei-lon; Suárez, Carlos Gómez; Mathe, Laszlo. Proceedings of the 2014 IEEE Vehicle Power and Propulsion Conference (VPPC). IEEE Press, 2014.
12. Multi-functional Converter with Integrated Motor Control, Battery Charging and Active Module Balancing for Electric Vehicular Application / Mathe, Laszlo; Schaltz, Erik; Teodorescu, Remus; Haddioui, Marcos Rejas. Proceedings of the 2014 IEEE Vehicle Power and Propulsion Conference (VPPC). IEEE Press, 2014. s. 1-5.

PhD dissertation

- Characterization, Modelling and State Estimation of Lithium-Sulfur Batteries, Knap, Vaclav, Aalborg Universitetsforlag, 2017. 197 s.

Working papers

- Battery charging through the motor winding using the inverter as an active rectifier

Trade journal articles

- Novel ISO compliance, Electric & Hybrid Vehicle Technology International, January 2016.

Student projects

1. Smart Modular Battery Packs (SMBP) with WiFi for Residential Energy Storage Systems (RESS), 6th semester, spring 2018
2. Control of Smart Modular Battery Packs (SMBP) for EV with WiFi feedback, 9th semester project, autumn 2017
3. Battery Charging for Electric Vehicles, 8th semester project, spring 2014

Workshops

- Pioneering Lithium Sulfur battery technology, Bob Hawkes, Oxis Energy Ltd., presentation at DBS/IDA seminar 'Emerging battery technologies – commercialization of the next generation', 17. November 2014.
- Advanced Management System for Li-Sulfur Batteries, Vaclav Knap, presentation at the Danish Battery Symposium 2015.

Other

- PhD student Vaclav Knap stayed 5 months at Cranfield University from February 1st 2016 to July 1st 2016