Oil & Gas Science and Technology – Rev. IFP Energies nouvelles (2016) **71**, 13
© O.M.F. Camacho and L. Mihet-Popa, published by IFP Energies nouvelles, 2014
DOI: 10.2516/ogst/2014001

OPEN ACCESS

Fast Charging and Smart Charging Tests for Electric Vehicles Batteries Using Renewable Energy

Oscar Mauricio Forero Camacho[1] and Lucian Mihet-Popa[1,2]*

[1] *Electrical Engineering Department-DTU, Frederiksborgvej 399, 4000 Roskilde - Denmark*
[2] *Politehnica University of Timisoara, V. Parvan 2, 300223 Timisoara - Romania*
e-mail: oscarmforero@gmail.com - lmih@elektro.dtu.dk - lucian.mihet@upt.ro

* Corresponding author

Abstract — *Electric Vehicles (EV) technologies are still relatively new and under strong development. Although some standardized solutions are being promoted and becoming a new trend, there is an outstanding need for common platforms and sharing of knowledge and core technologies. This paper presents the development of a test platform, including three Li-ion batteries designed for EV applications, and three associated bi-directional power converters, for testing impacts on different advanced loadings of EV batteries. Different charging algorithms/profiles have been tested, including constant current and power, and forced and pulsed power. The aim of the tests has been to study the impact of smart charging and fast charging on the power system, on the battery state of health and degradation, and to find out the limitations of the batteries for a Smart Grid. The paper outlines the advantages and disadvantages of both tests in terms of regulation of the aggregated local power, power capacity and the power exchange with the grid. The smart charging tests performed have demonstrated that even with a simple control algorithm, without any forecasting, it is possible to provide the required charging and at the same time the power system services, reducing the peak power and the energy losses in the power connection line of the power exchange with the national grid.*

Résumé — Tests de recharge rapide et intelligente de batteries pour voitures électriques utilisant des énergies renouvelables — Les développements technologiques liés aux voitures électriques (EV, *Electric Vehicles*) sont encore relativement nouveaux et s'intensifient. Même si certaines solutions standardisées sont encouragées et deviennent une nouvelle tendance, il y a un besoin exceptionnel pour des plateformes communes, mais aussi pour le partage de connaissances et de technologies de base. Cet article présente le développement d'une plateforme de tests, comprenant trois batteries Li-ion rechargeables conçues pour des voitures électriques, et trois convertisseurs de puissance bidirectionnels associés, permettant de tester l'impact de différentes stratégies de recharge sur les batteries. Différents algorithmes / profils de charge ont été testés, y compris à courant et puissance constants, et à puissance pulsée et forcée. L'objectif de ces tests est d'étudier l'impact de stratégies de recharge intelligente et rapide sur le système électrique, sur l'état électrique et la dégradation de la batterie, et aussi pour découvrir les limites des batteries dans un réseau électrique intelligent (*Smart Grid*). Cet article présente les avantages et les inconvénients de ces deux tests en termes de régulation de la puissance agrégée locale, de la puissance électrique installée et de l'échange de puissance électrique avec le réseau.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Les tests de recharge intelligente effectués ont aussi démontré que même avec un algorithme de contrôle simple, sans aucune prévision, il est possible de fournir la charge requise et dans le même temps les services du système d'alimentation, ce qui réduit la puissance de crête et les pertes d'énergie avec la connexion d'alimentation au réseau national d'électricité.

INTRODUCTION

Advanced energy storage devices and converters are introduced and tested recently for the next generation of Electric Vehicles (EV) for the smart grids. It is quite clear that the available technologies and its drivers are voltage-level independent and network structure independent [1-5]. The interest in these applications has been long-standing but the Battery Energy Storage System (BESS) technology had not matured sufficiently to warrant much interest. This is changing rapidly with the new generation of BESS using Li-ion batteries and state of the art power electronics converter topologies and control techniques [6-8].

Battery Management System (BMS) functionalities are very important for the optimal use and handling of batteries. The functionalities of the BMS could play a critical role to make an EV battery robust towards charging tests [9-13].

The different types of EV batteries have different characteristics regarding cost, energy density, safety, energy efficiency, degradation etc. making them suitable for different EV applications, such as Plug-in Hybrid Electric Vehicle (PHEV), many small cycles, full EV (many full cycles), fast charging or Vehicle-to-grid V_2G (cycles at high SOC (State of Charge)) [4-5].

Today, batteries are still a critical component in the EV industrialization due to their high price, technical complexity, limited records of long term operational data, etc. One of the most commonly selected Li-ion battery types for commercial electric vehicles is Li-ion manganese oxide based due to its overall balanced performance in energy/power densities, lifetime, cost and safety. At the same time, new Li-ion battery types started to show competitive key feature. Lithium-iron phosphate type was becoming a promising choice for PHEV's due to its high power/energy ratio favorable for Hybrid Electric Vehicle (HEV) and PHEV as well as improved safety and cycle life. On the other hand, mixed oxide based Li-ion types such as NMC (Ni, Mn and Co based) showed high energy density, which is crucial for the driving range started to be an interesting choice for EV's [4, 14-19].

Smart charging is one of the main challenges in EV mobility development. It is seen as indispensable to facilitate the optimal integration of EV to power system in order to avoid technical bottlenecks and the corresponding unnecessary investments in the electricity network [4, 20-22].

V_2G allows using EV to provide ancillary services to the electrical power grid. Additional grid services contribute to the optimization of energy use, for example, by the management of energy and power balance. Interaction with power grid needs bi-directional communication between EV and charging spots and bi-directional power flow. Therefore, the focus is on issues such as: reverse energy flow, control, communication and safety, which are the key issues in the future smart city concepts [23-25].

Fast charging should be able to charge a significant amount of energy (25÷75% of the battery's capacity) into the battery within 5÷15 minutes, depending on the actual application (typically for 150-200 km) [4-5].

Objectives

This paper is focus on testing of electric vehicle batteries to study the impact of smart charging and fast charging on the power system and on the battery degradation. Two different types of EV battery packs have been tested: a 16 kWh Lithium-Ferro type, optimized for hybrid EV applications, and a 26 kWh Lithium polymer type, optimized for full EV applications. The objectives of the smart charging are to address not only the charging needs specified by the user, but also to address the needs for power regulation in the power system. The objectives of the fast charging are to test different charging profiles and to study the impact on the charging efficiency and on the batteries.

Outline of the Paper

In the next section, we present some details about experimental facilities of SYSLAB. Section 2 provides the description of the topology, operation and battery management system with details about monitoring, protection and control of the battery pack systems. The experimental set-up, algorithm tests profile and results are presented in Section 3 for smart charging and fast charging, as well. Finally, concluding remarks are also presented.

1 SYSLAB-EXPERIMENTAL FACILITY OF A DISTRIBUTED ENERGY SYSTEM ARCHITECTURE

SYSLAB is a laboratory for research in distributed control and smart grids with a high share of renewable energy production. Its experimental facility is a Wind/PV/Diesel Hybrid Mini-Grid with local storage and a novel control infrastructure. The facility is spread across three sites located several hundred meters apart. At each of the three sites, there is a switchboard that allows the components installed at the site to be connected to either of two bus bars. The bus bars can be either connected to the national grid or can be part of an isolated system, as it is shown in Figure 1.

It includes two wind turbines (10 kW and 11 kW), three PV-plants (7.2 kW and 2 × 10 kW), a Diesel gen-set (48 kW/60 kVA), an intelligent office building with controllable loads (10 kW), a number of loads (75 kW, 3 × 36 kW), a Vanadium Redox Battery of 15 kW/120 kWh and three containers, each with an EV battery pack and a bidirectional power converter (*Fig. 2*).

Under the tests reported in this paper the SYSLAB power system has been operated as a micro-grid connected to the national grid, emulating a local part of a larger power system. In addition to the EV batteries, the micro-grid includes wind power, solar power and flexible loads representing future consumers. The batteries can switch between being connected either to the micro-grid or direct to the national grid through dedicated grid connections, emulating grid connected state or driving state, respectively, as can also be seen in Figure 2.

2 TOPOLOGY, CONTROL AND OPERATION OF THE BATTERY SYSTEM

This section covers the description of the battery management system with details about monitoring and

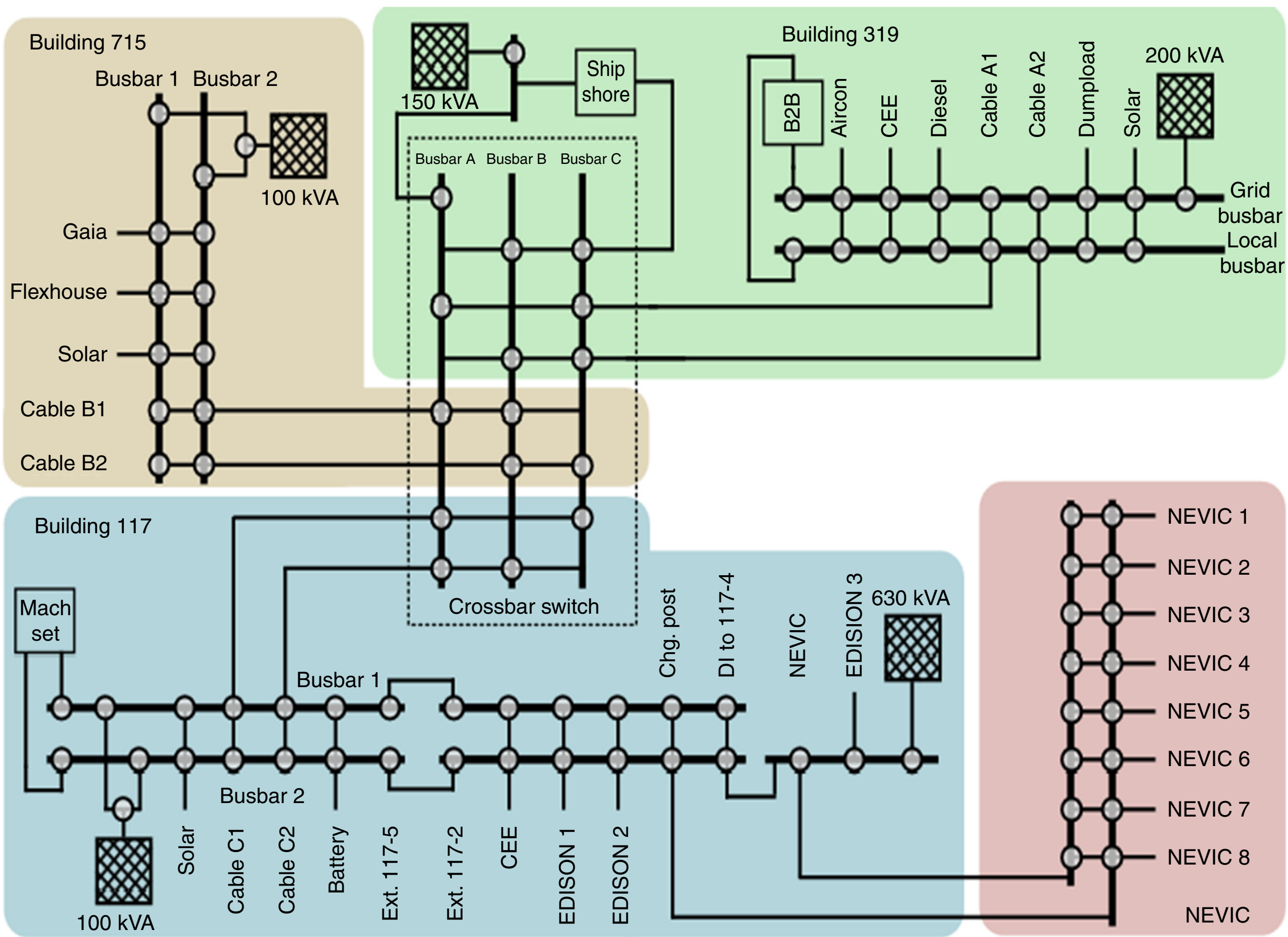

Figure 1

SYSLAB - DTU Risø's new laboratory for intelligent, active and distributed power systems.

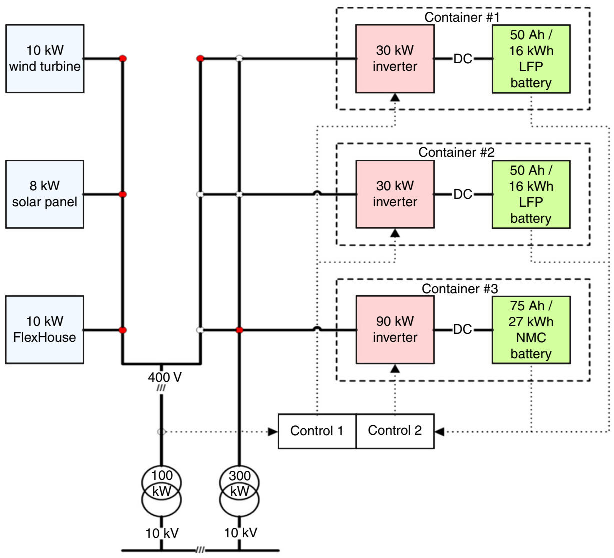

Figure 2

The power grid connection options of the EV batteries and their inverters to the SYSLAB power systems.

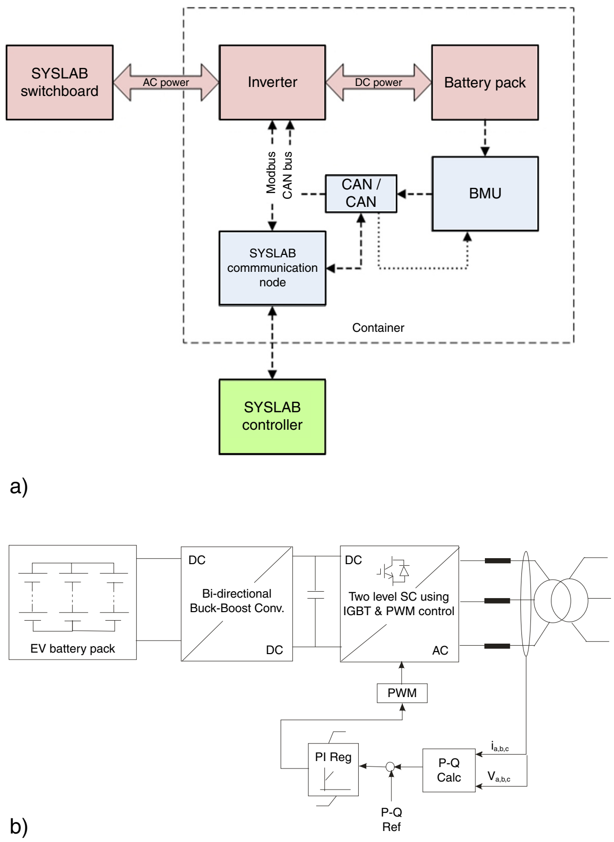

Figure 3

a) Details about the communication and control of the test platform including EV battery pack, bidirectional converter and external controller; b) the block diagram of the BESS topology with its two-level bi-directional power converter using IGBT and PWM control.

protection of the battery, communication technologies and interfaces to enable open network communication and interoperability. Also, a block diagram of the BESS topology, including the bi-directional Voltage Source Converter (VSC), is presented.

The EV batteries packs are equipped with a dedicated BMS, monitoring the states of the individual cells in terms of voltage, current and temperature. The test set-up (as it is shown in *Fig. 3*) covers an individual BMS, a Controller Area Network (CAN-CAN) converter and a bidirectional power converter; the set-up also protects the battery from being overloaded by external load requests.

The BMS monitors the state of the individual cells, and sends a request to the inverter to reduce the power, controlling the power flow to and from the battery, in order to protect the battery from being overloaded by an external load request.

Individual CAN-CAN converters have been developed and inserted between the BMS and the inverters, monitoring the communication between them and establishing an appropriate communication.

The bidirectional inverter is able to control the power flow to and from the battery within the specified limitations using its integrated control panel and also by external communications. The block diagram of the BESS topology, including the bidirectional power converter is shown in Figure 3b. The power converter contains a DC-DC bidirectional buck-boost converter and a Pulse With Modulation (PWM) VSC. A current-controlled voltage source, using active and reactive power loops with PI-regulators, is used. The active current component is used to control the DC link voltage and, consequently, the inverter active power output, in order to balance the EV battery and inverter active output power. The reactive current component controls the inverter's reactive output power.

The inverter communication ports are: an Ethernet port for communication with the SYSLAB communication node (Modbus TCP) and a CAN port for communication with the BMS, as can also be seen in Figure 3a.

The various test load patterns are controlled from dedicated controllers implemented on SYSLAB. From the SYSLAB controller the power flow to/from the batteries can be controlled in either current or power control mode independent of the sign of the control parameter. The power flows to and from the batteries are fully controlled by the SYSLAB controller.

3 EXPERIMENTAL TESTS AND RESULTS

The test platform includes three test benches in individual containers (for safety), each with an EV battery pack and a bidirectional converter to control the power flow to and from the battery, as it was shown in Figure 3.

Two of the inverters have capacities of 80 A, and the 3rd one has a capacity of 210 A, used for fast charging testing.

Two types of batteries were tested: a *BYD* 50 Ah/16 kWh Lithium-Ferro-Phosphate [25], suitable for HEV applications, and a *Kokam* 75 Ah/26 kWh Lithium-Polymer (NMC) [26], suitable for EV applications. More details can be find out in Appendix. Each battery pack is equipped with a dedicated BMS to monitor the voltages, currents and temperatures of the individual cells, and, if necessary, sending requests to the inverters to reduce the current in order to protect the battery against overloading.

3.1 Smart Charging

Smart charging covers all types of regulated charging with an additional objective, to the fully charging of the battery with maximum power. The objective of this test is to address not only the charging needs specified by the user but also the needs for power regulation in the power system. The "smart" control of the charging ensures full charging of the battery within a given period, but schedules the charging within the period relative to the local power balance.

This test is made with real components of the SYSLAB, including a 10 kW wind turbine, an 8 kW PV system and the consumption from a 10 kW office building, as can be seen in Figure 4.

The test emulates that the EV (battery) alternates between driving and being connected to the grid for charging. While "driving" (discharging the battery), the inverter is connected directly to the national grid and while "charging" the inverter is connected to the local power system.

The tests have been performed with a series of 6 hours driving-charging tests cycles with the driving loads emulating real driving patterns (based on vehicle driving data recorded in the Copenhagen area by GPS loggers, as part of the AKTA project [27]), as can be seen in Figure 5.

In Figure 6 is presented an example of the smart charging test cycling of the BYD battery with a driving load based on AKTA driving pattern.

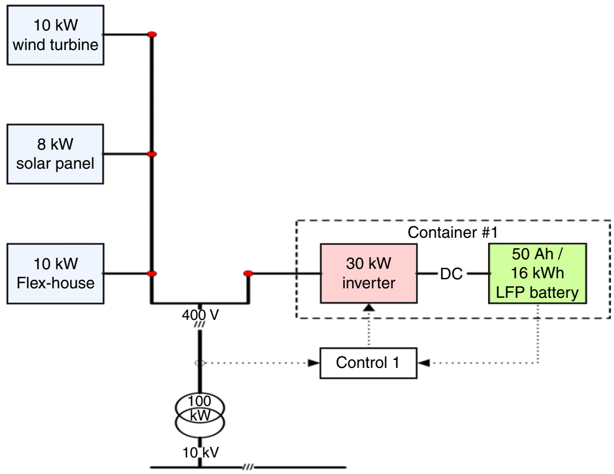

Figure 4

The set-up for smart charging tests.

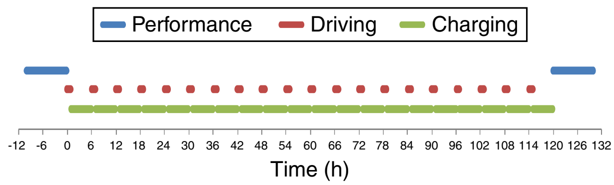

Figure 5

The "smart" charging tests alternates between one hour driving (time in which a single driving day is perform) and six hours charge modes and performance test at regular intervals.

As can be seen in Figure 6 are shown the BYD battery parameters which have been monitored during the smart charging test, such as the battery pack DC power, current and voltage (from the top), the maximum and minimum cell voltage and a comparison between the battery temperature, the maximum and minimum cell temperature during the test.

The developed smart charging strategy focuses on fulfilling the charging needs and constrains of EV owner (in this case, the battery must be fully charged in maximum 6 hours) and also focus on supplying power system services such as power regulation and load shifting. Additionally, the battery constrains are taken into account, so that a maximum charging current is set to a limit of C/3.

Hence, the charge process is accomplished by fully charging the battery within the specified time and scheduling the charge according to the power balance of the local grid:

$$P_{generation} = P_{consumption} + P_{losses}$$

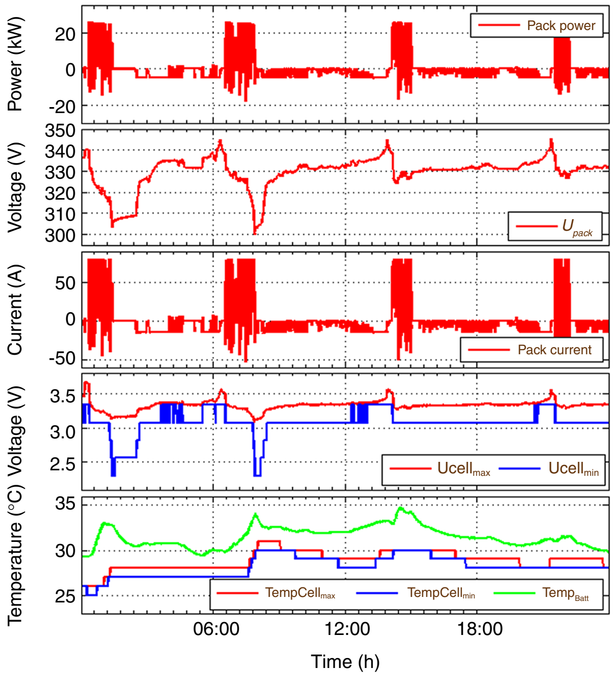

Figure 6

Driving load based on AKTA driving pattern and the EV battery load model.

in which:

$$P_{generation} = P_{wind} + P_{PV}$$

and

$$P_{consumption} = P_{Flex\text{-}house}$$

The designed control algorithm for smart charging, implemented as SYSLAB controller block (*Fig. 3*), is based on: the higher local aggregated excess power, P_x, the less charging flexibility, C_x, and the higher charging power, P_c. The local aggregated excess power, P_x, is defined as:

$$P_x = P_w + P_s - P_h \tag{1}$$

where P_w is the wind turbine power, P_s is the PV solar power and P_h is the Flex-house power.

The charging flexibility, C_x, which represents a number between [0÷1], where 0 means no flexibility and 1 means full flexibility, could be defined as:

$$C_x = 1 - T_{c\_\min}/T_c \tag{2}$$

where T_c is the remaining charging time and its minimum value could be express as:

$$T_{c\_\min} = E_c/P_{c\_\max} \tag{3}$$

in which E_c represents the remaining required charging energy and P_{c_max} is the maximum charging power.

In charging mode the charging power is giving by:

$$P_c = k_p \cdot (P_x - P_{x,e}) - k_c \cdot \log(T_c \cdot P_{c\_\max}/E_c - 1) \tag{4}$$

where $P_{x,e}$ is the "expected" aggregated excess power at the actual time of the day and k_p and k_c are weighting constants. Since the first terms from (4) represent the power system needs k_p expresses the deviation of the actual aggregated excess power (positive when the actual aggregated excess power is higher than expected and negative otherwise). Also, because the second part from (4) represents the charging needs, negative when the charging flexibility is high and positive when flexibility is low, k_c can be set up accordingly.

A flow diagram of the active power control algorithm for smart charging, based in Equations (1-4) and the assumptions presented in this section, is show in Figure 7.

An example of the smart charging is presented in Figure 8, monitoring the current and the voltage of the battery pack, which are the inputs for the inverter. It can also be seen how the charging current is controlled according to the defined algorithm, based on (1) ÷ (4).

The impact of the smart charging on the power exchange to the public grid is illustrated in Figure 9. In Figure 9a is presented the output power during a day (for around 6 hours) for each component-power production (wind power and solar power), power consumption (representing here by Flex-house) and the charging power of the battery (P_c). In Figure 9b is presented a comparison between total power (P_x) exchange to the public grid with and without considering charging power of the battery (P_c). The influence of the charging power of the EV on the total power of DER components, in order to balance the grid power, is also pointed out in Figure 9b.

3.2 Fast Charging

The objectives of the fast charging tests are to test different charging profiles impact on the charging efficiency and on the battery. This method has been tested with many cycles of fast charging and slow discharging at different power levels, SOC levels and charging energy.

In Figure 10 is presented a block diagram of the set-up with the high power inverter and EV battery used for the fast charging tests.

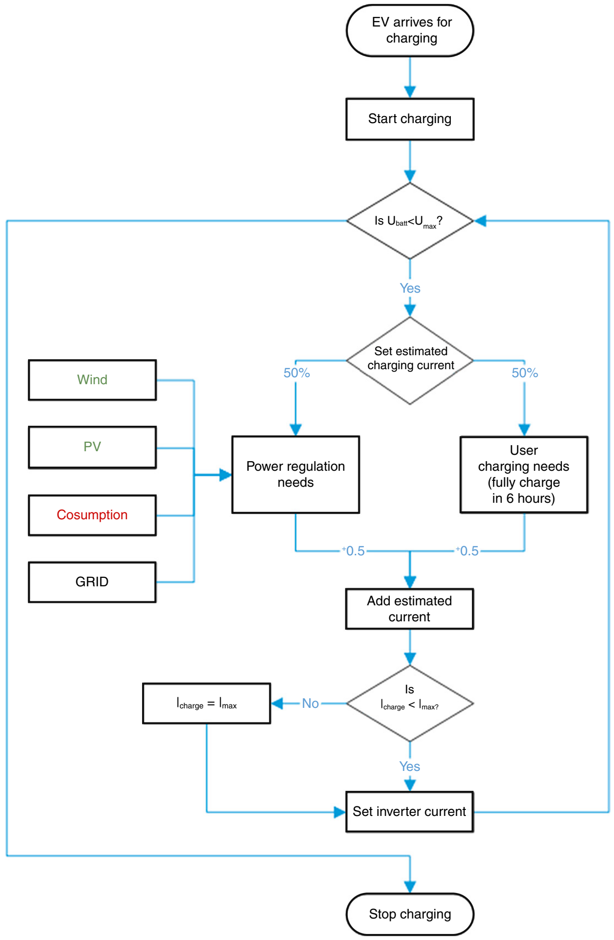

Figure 7

A flow chart diagram of the active power control algorithm for the smart charging strategy.

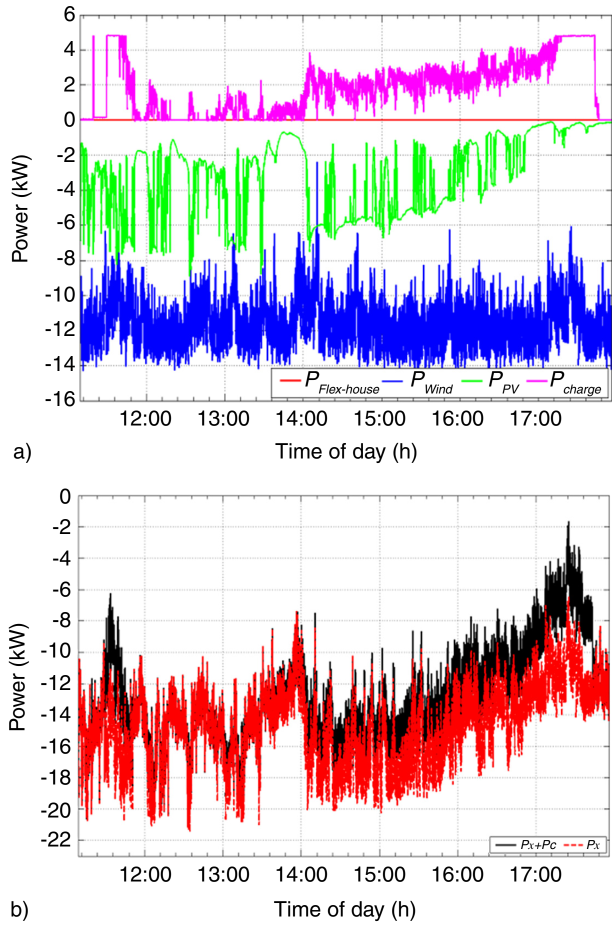

Figure 9

a) Power exchange to the public grid of the individual components, and b) a comparison of the power exchange to the power grid with and without the smart charging power.

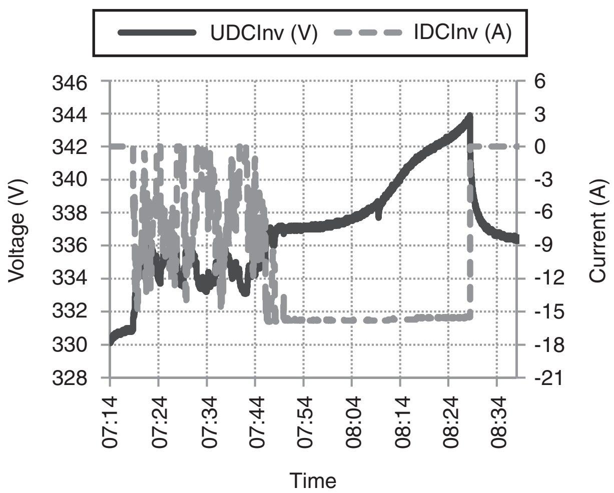

Figure 8

The battery packs current and voltage during a smart charging cycle.

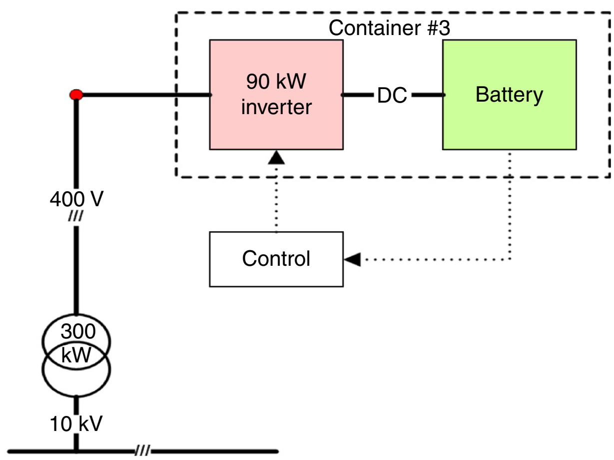

Figure 10

The power connection of the EV battery and its inverter for fast charging tests.

TABLE 1

An overview of the different charging profiles tested

Profile	Charging characteristics
Constant Current (CC)	The battery is charged with CC until the required energy has been charged or the charging power is limited by battery constrains
Constant Power (CP)	The battery is charged with constant power until the required energy has been charged or the charging power is limited by the battery constrains
Forced Power (FP)	The charging power is gradually reduced until the required energy has been charged or the charging power is limited by the battery constrains

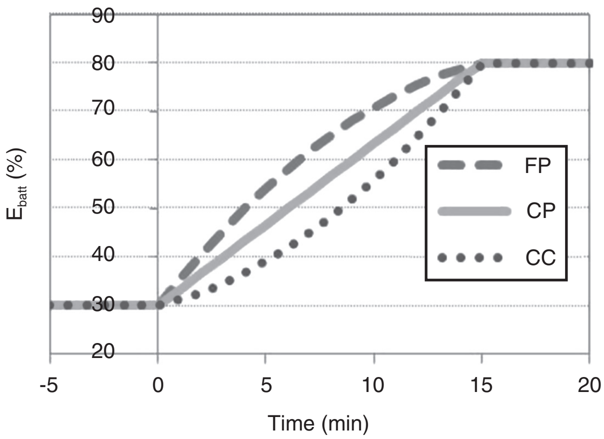

Figure 11

The estimated stored energy in the battery during the planned fast charging strategies for 50% energy charged in 15 minutes for three charging profiles: CC, CP and FP.

Different charging profiles have been tested. An overview of these profiles is given in Table 1, including Constant Current (CC), Constant Power (CP), and Forced Power (FP).

To point out the difference between charging profiles a comparison is shown in Figure 11. The different charging profiles reach a given amount of charged energy within a given time, 15 minutes in Figure 11, and independently of the profile.

With the limited cooling of the batteries in the tests, there were found very little differences between the different charging profiles.

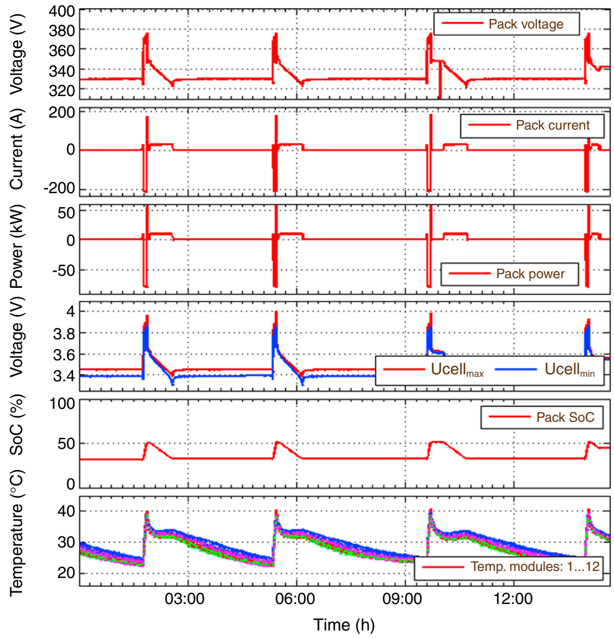

Figure 12

Example of a repeated fast charging test cycling of the *Kokam* battery with a charge energy of 13 kWh (40% of SOC) at constant current of 3C (210 A) and discharging with C/3 (25 A).

An example of the repeated fast charging tests cycles with a constant power is presented in Figure 12.

The temperature increases very fast from around 25°C to around 40°C and as the voltage increases with the SOC level the charging current decreases during the fast charging.

Since the voltage of the *Kokam* battery increases constantly with the SOC over the full range this makes possible to use it in combination with temperature to estimate the SOC, and allows identifying the fully charged/discharged states by checking the specified maximum/minimum cells voltage. It means that the current must be limited when it is closed to fully charged/discharged.

In Figure 13 is presented a detail with a comparison between CC, CP and FP profiles during fast charging tests of the *Kokam* battery. The SOC is difficult to be estimated under normal operation and because of that cannot be used as an accurate measure, but only as an indicator.

The SOC will decrease/increase linearly when the battery is discharged/charged with constant power, but not when the battery is discharged/charged with constant current (and variable voltage).

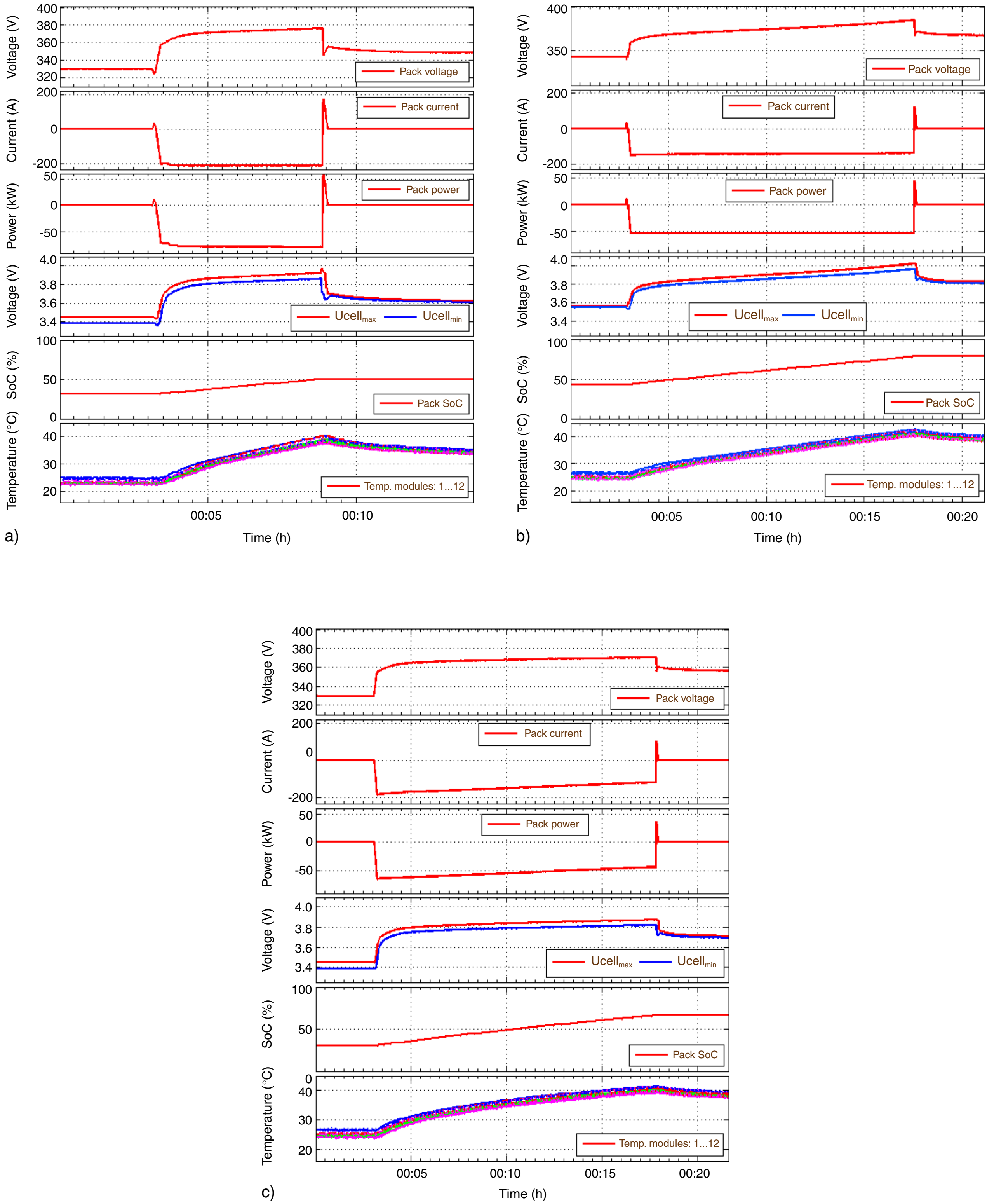

Figure 13

Details of the fast charging with a charge energy of 6.5 kWh (50% of SOC) for a) constant current at 2 C (210 A), b) constant power at 52 kW, and c) forced power from 60 kW to 44 kW.

As can also be seen in Figure 13, the charging power to the EV battery is not only limited by the capacity of the charging unit, but also by the maximum charging current, the temperature and by the SOC. As the internal cell temperature cannot be measured directly, and therefore not accurately, the charging current is gradually reduced by the Battery Management Unit (BMU) when the temperature reaches the given maximum temperature.

As a comparison between CC (*Fig. 13a*) and CP (*Fig. 13b*), when the voltage increases with the SOC, the charging power will also increase, during the CC profile, whereas during the CP profile, when the voltage increases with the SOC, the charging current decreases. During the FP profile (*Fig. 13c*) as the voltage is lowest at the beginning of the charging, the charging current is very high, as well.

CONCLUSIONS

In this paper, we have presented the development of a test platform, including three Li-ion batteries, designed for EV applications, and three associated bi-directional power converters, for testing impacts on different advanced loadings of EV batteries.

The smart charging tests performed have demonstrated that even with a simple control algorithm it is possible to provide a required charging energy within a given period of time and to provide power system services in terms of regulation of the aggregated local power, reducing the peak power and the total energy exchange of the power exchange with the national grid. Fast charging tests have been performed with constant power, constant current and forced power at charging rates corresponding to a double (2C) and triple (3C) capacity. The constant power gives the lowest impact on the grid and the main limitation of the *Kokam* battery seems to be the fast increase of the temperature.

For future battery design, this could be addressed through build-in cooling systems and/or through increased thermal capacity of the cells.

As a future work we will build a simulation model based on the tests reported in this paper which will describe the dynamic behavior of the batteries packs as a function of SOC and cell temperature to be used in a power system analysis tool to design different scenarios for a future smart grid.

ACKNOWLEDGMENTS

This work was supported in part by the Project-EDISON, No. 10580/2011-2012.

The authors would like to thanks to Per Nørgard for interesting discussion and his valuable suggestions during the tests.

REFERENCES

1 Dow L., Marshall M., Xu L., Aguero J.R., Willis H.L. (2010) A novel approach for evaluating the impact of electric vehicles on the power distribution system, *IEEE PES General Meeting 2010*, 25-29 July, Minneapolis, USA.

2 Wu X., Toshihiro M., Hisashi F. (2012) Three-phase high frequency transformer isolated AC to DC converter for EV battery quick charging, *Proc. of 7th IEEE-ECCE Conf.*, 2-5 June, Harbin, China.

3 Richardson K., Dahl-Jensen D., Elmeskov J., Hagem C., Henningsen J., Korstgård J.A., Kristensen N.B., Morthorst P.E., Olesen J.E., Wier M. (2010) Green energy - the road to a Danish energy system without fossil fuels, *Danish Commission on Climate Change Policy*.

4 Norgard P., Forero Camacho O.M., Rao N. (2012) Electric vehicles in a distributed and integrated market using sustainable energy and open network, *Riso-R-1753 Report*, Roskilde, Denmark.

5 Website: http://www.edison-net.dk/, A. Foosnæs, Electric vehicle technology, *EDISON WP1.1 report*, 2010

6 Ekanayake J., Jenkins L., Wu J., Yokoyama A. (2012) *Smart Grid: Technology and Applications*, John Willey & Sons, Chichester, England.

7 Simoes M.G., Roche R., Kyriakides E., Suryanarayanan S., Blunier B., McBee K.D., Nguyen P.H., Ribeiro P.F., Miraoui A. (2012) AQ comparison of smart grid technologies and progresses in Europe and the U.S., *IEEE Transactions on Industry Applications* **48**, 1154-1162.

8 Cha T.C., Zhao H., Wu Q., Saleem A., Østergard J. (2012) Coordinated control scheme of Battery Energy Storage System (BESS) and distributed generations (DGs) for electric distribution grid operation, *Proc. of the IEEE IECON 2012 – the 38th Annual Conference on Industrial Electronics Society*, 25-28 Oct., Montreal-Canada.

9 Sista S., Sista A. (2013) Intelligent BMS solution using AI prognostic SPA, *Lecture notes in Electrical Engineering Journal* **192**, 4, 755-764.

10 Wu C., Wan J., Zhao G. (2012) Addressing human factors in electric vehicle system design: building an integrated computational human-electric vehicle framework, *ELSEVIER Journal of Power Sources* **214**, 319-329.

11 Yan X., Li W., Gu J., Xiao X., Li W. (2012) A simulated system of battery management system to test electric vehicles charger, *Proc. 2012 IEEE IEVC Conf.*, pp.183-197.

12 He H., Xiong R., Guo H., Li S. (2012) Comparison study on the battery models used for the energy management of batteries in electric vehicles, *ELSEVIER Energy Conversion and Management Journal* **64**, 113-121.

13 Davide A. (2010) *Battery Management Systems for Large Lithium-Ion Battery Packs*, Artech House book, London. ISBN 13 978-1-60807-104-3.

14 Lee S.S., Kim H.T., Hu S.J., Cai W.W., Abell J.A. (2010) Joining technologies for automotive lithium-ion battery manufacturing - A review, *International Manufacturing Science and Engineering Conference*, 20-22 May, Michigan, USA.

15 Xin S., Guo Y.G., Wan L.J. (2012) Nanocarbon networks for advanced rechargeable lithium batteries, *Accounts for Chemical Research Journal* 45, 10, 1759-1769.

16 Sundararagavan S., Baker E. (2012) Evaluating energy storage technologies for wind power integration, *Solar Energy Journal* **86**, 9, 2707-2717.

17 Marinescu D.G., Tabacu I., Serban F., Viorel N., Tabacu S., Vieru I. (2013) Plug-in hybrid vehicle with a lithium iron phosphate battery traction type, *Lecture Notes in Electrical Engineering Journal* **191**, 3, 449-461.

18 Rao N. (2012) Interplay between EV battery and Power Grid, *EV battery forum*, Barcelona, Spain.

19 Website: http://www.trafikstyrelsen.dk/DA/Groen-Transport/Elbiler/~/media/7700C7669AB44627BCDC7CDE075ADBE3.ashx

20 *International Electrotechnical Commission IEC 61851–1 Standard* (2010) Electric vehicle conductive charging system.

21 Kenichi M. (2012) Information and communication technology and electric vehicles-Paving the way towards a smart community, *IEICE Transaction on Communication System for Electric Vehicle Charging Journal* **E95B**, 6, 1902-1910.

22 Fei X., Xianzhang L., Yebiao Z., Hongchao L., Ciurei G. (2012) A complex network-based method to evaluate smart charging and swapping network for electrical vehicles, *Power System Technology Journal* **36**, 9, 20-24.

23 Yujin L., Hak-Man K., Sanggil K., Tai-Hoon K. (2012) Vehicle-to-grid communication system for EV charging, *Integrated Computer-Aided Engineering Journal* **19**, 1, 57-65.

24 Sortomme E., El-Sharkawi M.A. (2012) Optimal scheduling of vehicle-to-grid energy and ancillary services, *IEEE Transactions on Smart Grid* **3**, No. 1.

25 Website: http://www.raesystems.com/sites/default/files/downloads/MSDS_Lithium_Ion_Battery.pdf, BYD Battery parameters, BYD Company Limited FV 50 cells

26 Website: http://www.kokam.com/product/product_pdf, Technical specifications of Kokam battery

27 AKTA (2003) The road pricing experiment in Copenhagen, *DTU Technical Report*, Roskilde, Denmark.

Manuscript accepted in January 2014
Published online in May 2014

Cite this article as: O.M.F. Camacho and L. Mihet-Popa (2014). Fast Charging and Smart Charging Tests for Electric Vehicles Batteries Using Renewable Energy, *Oil Gas Sci. Technol* **71**, 13.

APPENDIX

TABLE A1
Main specification of the battery packs tested in this paper

Manufacturer	*BYD*	*Kokam*
Model	FV 50 F3DM Fe	SLPB 75
Type	Lithium-Ferro-Phosphate	Lithium Polymer
Typical application	PHEV	EV
Nr. of modules	10 (each with 10)	12 (each with 8)
Nr. of cells	100	96
Nominal voltage	320 V	350 V
Capacity	50 Ah/16 kWh	75 Ah/26 kWh
Max cell voltage	3.6 V	4.15 V
Min cell voltage	2 V	3 V
Max charging current	100(300) A	225 A
Max discharging current	300(600) A	450 A
Max temperature	55°C	45/55°C
Nr. of battery packs	2	1