Abstract

In Asia, Europe and North America more and more effort is being put into standardization, development and deployment of fast charging stations for electric vehicles. This will over the next few years create an increasing demand for off-the-shelf components to build the vehicle side of the fast charging infrastructure.

This paper will give a brief overview of the dominant standards within the field of fast charging and present a cheap, powerful and flexible solution to address the different fast charging standards from a global perspective. The paper will also briefly cover implementation of formal functional safety for fast charging application. Finally the paper will cover independent cell testing and characterization to enhance understanding of cell behavior and performance degradation of cells under fast charging condition.

Keywords: Fast charging, DC charging, functional safety, cell characterization, international standards

1 Introduction

The physical connection, topology and communication requirements for the Plug-In Electric Vehicle (PEV) fast charging are standardized by International Electrotechnical Commission (IEC), see [2] and [3].

Based on these standards several distinct fast charging methods are currently being commercialized with more emerging on the horizon. Some important implementations:

- A. CHAdeMO, direct current (DC) fast charging implementation that is the de facto standard in Japan
- B. GB/T, alternating current (AC) fast charging standard published in China
- C. COMBO/Combined Charging System (CCS), European DC fast charging standard

The Fast Charge Interface Module (FCIM) by Lithium Balance A/S provides the vehicle side implementation of the fast charging infrastructure. System of type A and C are supported right out of the box, but the FCIM has been designed using a modular concept that allows for fast adaptation for systems of type B as well as other upcoming fast charging solutions. The FCIM can be integrated or retrofitted onto any PEV thus reducing development cost and effort of new PEV with fast charge support.

The flexibility of the FCIM also simplifies support of an international distribution of a PEV, since the difficulty of managing various national standards is managed exclusively by the FCIM.

The FCIM can be integrated with any battery management system, but come prepared out of the box with a well-tested integration with the battery management systems from Lithium Balance A/S.
Besides implementing DC fast charge vehicle side support it is relevant to study what impact does fast charge (high C rate, ≥2C) have on PEV battery pack. It is generally assumed that the fast charge can significantly decrease the useful life of the battery, however few results are available on the matter and there are reasons to argue that fast charge in itself does not significantly decrease the useful life of the battery, but the side effects of fast charge (especially increased temperature due to internal resistance) plays more significant role in the decrease of useful life when fast charging the battery pack [1].

2 Fast Charge Interface Module
Fast Charge Interface Unit (FCIM) implements the vehicle side of the fast charging infrastructure for systems of type A and C. The advantages of implementing the vehicle side of the fast charging in a stand-alone module include:

- Reduction of development cost and time to market for new PEV products
- Possibility to retrofit fast charging support in existing PEV fleets
- Support for multiple fast charging standards within a single PEV product line can be managed by replacement of only the FCIM (and the associated fast charging plug in most cases)
- Possible to sell fast charging support as an optional module hence supporting product diversification

2.1 Analysis of standards
To identify the requirements for the development of the FCIM many standards and implementations of fast charging were analysed. The results of this analysis for two selected implementations are briefly summarized in table 1.

Table 1: Analysis of DC fast charging standards

<table>
<thead>
<tr>
<th></th>
<th>CHAdE MO</th>
<th>CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication physical</td>
<td>CAN</td>
<td>GreenPHY PLC</td>
</tr>
<tr>
<td>Communication data</td>
<td>Custom CAN</td>
<td>Network: IPv6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport: TCP, UDP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Session: V2GTP, HTTP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Presentation:</td>
</tr>
</tbody>
</table>

2.2 Requirement specification
To achieve an effective implementation of a FCIM for real life application it is important to understand how the FCIM will fit into the overall functional and safety architecture of the PEV. The analysis takes a PEV without fast charging support as the starting point. The key components of the PEV that are involved in the implementation of the fast charging are:

1. The battery management system (BMS). Arguably the most important actor in the implementation of the fast charging the BMS is responsible for setting set points ofr allowed charge current, maintaining safe and reliable operation of the battery and communicating all relevant battery diagnostic data on the Controller Area Network (CAN)
2. The vehicle control unit (VCU). The vehicle control unit may or may not interact with the BMS to set the system into “charge mode” and provide the vehicle driver with information about charge status.
3. The on-board charger, should in most cases be disconnected during fast charging but needs to be considered in the functional and safety analysis of the fast charging solution.

In order to keep the FCIM simple to integrate and universally applicable the interface has been
limited to a CAN bus interface to the BMS. Any information to the driver or charger will be managed by the BMS, just as if the vehicle as charging using the on-board charger. The FCIM uses the information from the BMS to control the fast charging process in a way that is consistent with the safe operational parameters set by the BMS. See figure 1.

Figure 1: General FCIM design logic

This architecture supports fast charging using both systems of type A (CHAdeMO) and C (CCS), provided the FCIM is engineered to comply with a number of system level requirements:

- One CAN bus interface to the BMS and other PEV systems
- One CAN bus interface to CHAdeMO chargers. This interface must be galvanically isolated from the BMS interface.
- Driver output for relays controlling the connection to the charger
- Power line communication (PLC) interface to CCS chargers.
- Diagnostics of the charging process
- Data logging for the CAN bus traffic for diagnostic purposes
- Processing capability to support communication on two high-speed CAN bus networks at once

2.3 Functional safety

The FCIM fills a non-trivial role in the safety architecture of the fast charging solution. On one hand you have the energy storage system (ESS) of the PEV, with many safety requirements relating to fire hazards, electrical hazards and so forth. On the other hand we have the charging station with a safety architecture relating to electrical hazards, grounding faults, sparks etc.

In between these two safety critical systems you will find the FCIM. In summary;

1) The BMS is responsible for maintaining the safety of the battery pack at all times.

2) The charging station is responsible for maintaining the safety of the charging post and the user at all times.

3) The FCIM is included in both safety cases and acts as a bridge between the two.

Since both the charging station and the BMS will detect and react to malfunctions in the FCIM it is imperative that the FCIM maintains a very high level of reliability.

In order to accomplish this the FCIM has been designed in accordance using exclusively highly reliable automotive grade components, a EMC robust 6 layer board design and an automotive safety integrity level (ASIL) D rated microcontroller suitable for safety critical subsystems in road vehicles.

2.4 Hardware design considerations

The CHAdeMO implementation is technically straightforward since it does not include the highly specialized PLC communication used by CCS. Furthermore the CCS implementation largely uses the same elements as the CHAdeMO implementation.

Based on these two observations the FCIM was designed as;

a) A base platform that contains all functionality required to support CHAdeMO fast charging.

b) A modular concept of expansion modules where the first module developed is used to support the CCS standard. Future modules can be developed to support other fast charging standards.

Using this modular topology it is possible to address both standards without incurring extra cost due to superfluous hardware components for either implementation. It also makes the FCIM a platform secured for the future by assuring that upcoming fast charging standards can be supported with a minimum of effort.

2.4.1 Base platform

To cover the requirement for the data communication the base platform supports two galvanically isolated CAN bus interfaces in order to accommodate the interface with on-board systems and separate bus with the charger.
To meet the electrical requirements of the CHAdEMO specification the base platform contains three outputs capable of driving PEV high power relays with typical specifications.

To cover the requirement of data recording (logging) the base platform supports data logging to an automotive grade Secure Digital (SD) card and a real time clock (RTC) with a 10 year on-board battery to add time stamps to the data logging.

To cover the requirement of supporting multiple standards the system is designed including two detachable expansion modules which are able to communicate with base platform and control independent I/O’s directly.

2.4.2 CCS expansion module
To cover the requirement for the data communication the CCS expansion module includes a PLC communications modem.

To cover the requirement of hardware signals the expansion module includes dedicated IO controls according to the CCS specifications.

The CCS module is controlled directly from the base module using an internal high speed communication bus commonly used in automotive electronics designs.

2.4.3 Design reusability
The system designed for the support of fast charging is in fact a very flexible and powerful platform. The capability of adding new hardware functionality in the form of expansion modules as well as a boot loadable high performance safety rated automotive microcontroller gives the platform nearly limitless possible applications. Some examples include; CAN bridging, data logging, fleet management, VCU, DC charging system type B implementation, etc.

2.5 Firmware design consideration
2.5.1 Base platform
In order to accommodate functionality described in previous sections it is necessary to have a flexible firmware design with possibilities to configure the unit for different working environments (different vehicle systems, different uses of platform etc.). Hence the firmware is designed to allow customization of the platform functionality via firmware/settings during vehicle integration.

Figure 2: General FCIM base platform firmware design

2.5.2 Expansion module
The expansion module is designed to run its own customized firmware supporting the protocol and application layer of the CCS standard. The main challenges in regards to implementing the expansion module firmware for CCS fast charging is the implementation of the communications protocol stack.

The communications protocol stack for the CCS follows the Open Systems Interconnection model (OSI) and identifies the requirements for implementing common internet based protocols with addition to some custom protocols that are fast charging specific for type C. This includes the requirement for IPv6, TCP implementation alongside with XML parser implementation for session and application layers.

3 Fast charging applications
The most well-known application of fast charging is a public charging station somewhere alongside the highway or in a parking lot in city centre. This identifies the primary application group for the FCIM – the private PEV.

Private EVs are increasing trend in the society as means of cheaper (fuel wise) and cleaner (emissions wise) means of transport, which is becoming more and more relevant due to more strict standards for emission regulation, decreasing...
prices on PEV’s and an increased public environmental awareness.

In industrial, public and commercial application there are already charging infrastructures in place for fleets of electric vehicles (powered predominantly by lead acid batteries). In this segment the application of a fast charging infrastructure seems like a logical next step. This defines the secondary application group for the FCIM – the industrial PEV.

3.1 Private PEV

One key driver for the introduction of a fast charge interface in a private PEV is to make it more attractive for a customer in terms of reducing the so called “range anxiety” which is a common phenomenon when people consider using/buying an EV. Providing the drivers with fast charge capability and charging network increases the attractiveness of EV by reducing the charging time (closing the gap between time that takes to fill up a gas tank in standard vehicle and charging an EV) and enabling the driver to make long range trips (trips that would require the driver to charge EV at least once).

In this area the FCIM provides the manufacturers of PEVs with simple and straightforward implementation for common fast charge standards.

3.2 Industrial PEV

Industrial EVs such as forklifts, trucks, garbage trucks, light transporters etc. is another attractive market for use of FCIM. Providing a facility to reduce charge times means a higher utilization of the PEV, less downtime and faster return of investment of the vehicle purchase.

While regular charging is sufficient to cover the vast majority to travel distances for private PEV’s [5] and the role of fast charging can be considered mostly psychological for this segment the industrial PEV fast charging can in fact bring about radical improvement in fleet utilization.

Furthermore, when considering fast response vehicles (fire trucks, ambulances etc.) fast charging could be considered a requirement by end customers to enable electric drives in these vehicles.

Often private fleets and industrial PEVs use custom made chargers and charging systems. Often they are chosen due to lack of information and relatively more complicated implementation/conformance with charging system standards specified in [2] and [3]. However conformance to such standards could be advantageous because of broad (and increasing) supply of chargers conforming to the mentioned standards. The benefits of using such charger would come in form of improved safety, service, maintenance and supply.

The FCIM is a great fit for such applications because often the manufacturers of such PEVs have low volume production (compared to series production of cars) thus making it challenging to develop proprietary systems for conformance with international fast charge standards.

4 Fast charging impact on battery life

When considering fast charging impact on batteries the common belief is that the fast charging will significantly decrease the useful life of battery, but in fact very little has actually been published on the long term effects of fast charging on lithium ion batteries.

However, recently some car manufacturers which offer fast charge in their PEVs have given their batteries the same extent of warranty periods independent on charging method applied which is one suggestion that the real world data collected indicates that the fast charging does not have any significant impact on battery life [4].

One published study [1] suggests that the fast charging might cause accelerated cell degradation due to physical limitations of cell, where cells swell and shrink during charge/discharge process. Other unofficial studies that Lithium Balance A/S has been given access to through our research network suggest that the impact on the battery life when fast charging can be associated with side effects that are caused by fast charge but not the fast charge process itself. From these side effects the most significant is considered the temperature increase on the battery cell due to the heat generated by the internal resistance which contributes to higher heat dissipation with higher currents.
In order to contribute to the knowledge base about the batteries and to support customers with the system design and integration of the battery packs in the design Lithium Balance A/S in cooperation with Danish Technical Institute (DTI) are currently performing tests on different battery cells that are available in the market and commonly used for different EV applications.

4.1 Battery tests

4.1.1 Objectives

The objectives of this test are as follows:

- Identify impact of fast charge at different C rates on battery life over extended periods of time.
- Identify the impact of fast charging at different ambient temperatures on battery life over extended periods of time.
- Analyse the results and identify correlation between cell temperatures, possible temperature increase on the cell during fast charging on the increase in battery life degradation.
- Identify possible test procedure and setup for further cell tests and offer the knowledge as an external service.

4.1.2 Units under test

For units under test market available cells with different chemistries are chosen. Cells are chosen based on common chemistries found in EVs in the market. The test includes cells with the following chemical compositions:

- Lithium Ferrophosphate (LFP)
- Nickel Manganese Cobalt Oxide (NMC)
- Lithium Titanate Oxide (LTO)

For each chemistry one cell model is chosen based on preliminary technical specification offered by cell manufacturers.

4.1.3 Test matrix

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Temp [°C]</th>
<th>C-rate</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>5</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The A, B and C refers to the cell type where:

- A – LFP
- B – NMC
- C – LTO

In case the manufacturer of the specific cell under test does not specify that 5C rate is achievable lower C rate which is equal to maximum C rate specified by the manufacturer shall be used. No cells with lower C rate than 2 is considered for the testing.

0.5C rate is used as a reference rate for “slow” or “normal” charging conditions.

4.1.4 Test procedure

Optimally the cells would be tested in environment where the temperature on the cell can be kept on the same level during the whole testing procedure to eliminate the impact of the heat generated by the cell. For such testing environment high precision cooling/heating chamber would be necessary. Unfortunately, such equipment is not available at the DTI thus the environment temperature in the test chamber shall be kept constant and the temperature on the cell surface shall be monitored and recorded.

The cells shall be cycled with the specified charging C rate and 0.5C discharge rate with 1/2h rest periods between the events. The discharge rate is chosen low to minimize the impact of discharge degradation on the test. The cells shall be cycled between 20% and 80% SoC.

After every 120 cycles the capacity and internal resistance is measured in performance test which is done at 25°C with 1C charge and discharge rate.

The test is run for 1080 cycles. This number is chosen taking into account cycles expected from a real-world vehicle.
4.1.5 Results

The results shall be analysed according to the objectives of the study stated in 4.1.1. The result report shall be available from Lithium Balance A/S and shall be presented after the tests have concluded.

It is expected that the test results shall be available early 2016.

5 Conclusion

The fast charging interface modules from Lithium Balance A/S provides a simple, safe and reliable solution to the vehicle side of fast charging. It can swiftly and conveniently be integrated in both electric vehicles for the consumer segment and into industrial vehicles.

Lithium Balance A/S supports the world wide adoption of standards for fast charging both by the development of novel products and by independent battery qualification and testing for fast charging application of commonly used battery chemistries.

References

[1] Current-induced transition from particle-by-particle to concurrent intercalation in phase-separating battery electrodes, Yiyang Li et al. Available at http://www.nature.com/


Authors

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