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Electric Vehicle Infrastructure Development: An Enabler for Electric Vehicle Adoption

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Abstract

Fast charge capabilities will enable the rapid growth of the EV market by minimizing vehicle downtime and extending vehicle range. Using fast charge technology, one 10-minute charge cycle can provide enough energy to allow an EV to operate for an extended range of 100 miles. A high current DC connector will be the bridge between the fast charger and the vehicle battery pack. The level III DC connector, currently in the Society of Automotive Engineers (SAE) J-1772 subcommittee, will meet applicable standards and enable EV vehicle fast charging adoption.

Keywords: fast charge, infrastructure

1 Introduction

Today's electric vehicles (EVs) will likely be equipped with on-board chargers, typically 3.3kW or 6.6kW. The most common method of charging the vehicle, called Level 1, is to use a standard electrical outlet (NEMA 5-20R), which in the United States is 120 volt, single-phase. Although 3-prong standard electrical outlets are present almost everywhere, Level I charging is not the preferred means of charging [1]. Depending on the battery type and capacity, it can take from eight to 30 hours to fully recharge a battery.

The Level II charging method uses permanently fastened Electric Vehicle Service Equipment (EVSE), wired to 208/240VAC. Depending on the battery type and capacity, Level II can recharge an EV in up to eight hours. But what if an eight-hour charge is not fast enough?

2 Why Fast Charge?

Level I and II charging times significantly limit EV applications and market acceptance. Level III charging, from an off-board charger, allows much faster flow of power to the battery through the use of Direct Current (DC), bypassing the on-board charger. The Level III chargers are designed to charge an EV's battery in 10 minutes or less, depending on battery chemistry and size.

Fast charging could alleviate "range anxiety" by supplementing at-home slow charging with convenient on-road charging at opportunistic charging points. In one 10-minute charge cycle, fast charge technology can provide enough energy to allow an EV to operate for another 100 miles. With a network of fast chargers, consumers could charge any time, anywhere – practical infrastructure akin to the gasoline fill-up model. This fast charge capability can help to enable rapid growth of the EV market by minimizing vehicle downtime. Fast charge infrastructure enables volume growth of practical EVs and plug-in hybrid electric vehicles (PHEVs). Fleets can fast charge during opportunistic breaks to maximize productive drive time.

Depending on battery chemistry and size, chargers are capable of recharging EV batteries within 10 minutes. A Level III connector is shown below (Fig.1).

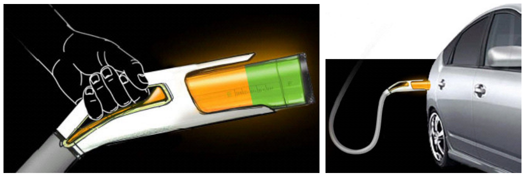


Figure 1: Level III Connector

Based on well established smart-charging technology, EV Fueling Stations could be the safe, convenient standard for public and fleet charging of the future – and will enable large volume adoption of the cleanest vehicles on the road.

With EV Fueling Stations, EV drivers are no longer tethered to their home-charging base. With a broad power range and Level III DC charging capability, EV range anxiety could be eliminated and provides a cleaner option for PHEV drivers who want to minimize traditional fuel consumption.

3 Fast Charger Technology and Design

EV Chargers are electronic-based and convert AC utility power into controlled DC power to charge an electric car battery pack. The charging system is intended for outdoor installation to operate in a manner that could be similar to existing gasoline pumps (Fig.2). Given the ubiquity of the electric transmission grid, these chargers could be located in a variety of locations, such as dedicated recharging stations (similar to gasoline stations), retail parking spaces, and supermarket parking lots. The charging process is intended to last no more than 10 minutes. Charging stations will be equipped with an intuitive human-machine-interface (HMI) to allow the customer to purchase electric energy using a variety of payment methods.

Figure 2: Level III On-road Charging Station

The EV Level III charger should integrate into its environment in a highly visible and attractive manner. The charger design must meet all regulations for automotive, electric outdoor equipment, while providing a simple interface for ease-of-use and acceptance by the customers. The charging module is capable of operating from 3-phase utility input voltage ranging from 400-600VAC (50or 60Hz) and delivering up to 600Amps DC to charge battery packs up to 750VDC. A 250kW charger, for example, is capable of charging a 35kWh battery pack (0-100% SOC) in less than 10min. The charger was designed to meet critical reliability, cost and flexibility requirements. The charger topology is based on off-the-shelf IGBT-based advanced integrated power modules designed and validated for automotive applications. The front–end power electronics module allows for operation at close to unity power factor.

Table 1 shows the relationship between the charger size, time to charge, state of charge, and type of vehicles.

Table 1: Relationships Among Charge, Charger Type and Different Vehicles

Type of Charge	Charger Power Level, kW		
	Heavy Duty	SUV/Sedan	Small Sedan
Fast Charge, 10 minutes, 100% SOC	500	250	125
Rapid Charge, 15 minutes, 60% SOC	250	125	60
Quick Charge, 60 minutes, 70% SOC	75	35	20
Plug-In Hybrid, 30 Minutes	40	20	10

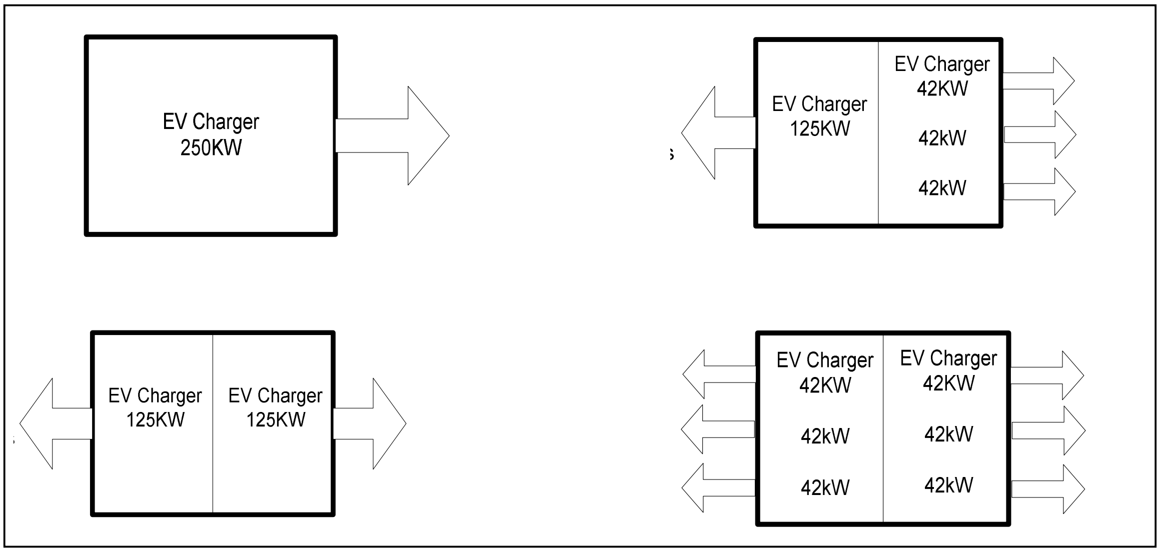


Figure 3: 250kW Level III EV Charger – Multi-port Capability

Similar to industrial forklift chargers, a 250kW charger could support multi-port applications as shown above (Fig.3). The multi-port feature allows fast charging up to six batteries, each with various energy capacity and chemistries, at the same time.

The basic specifications for a range of level III charger are:

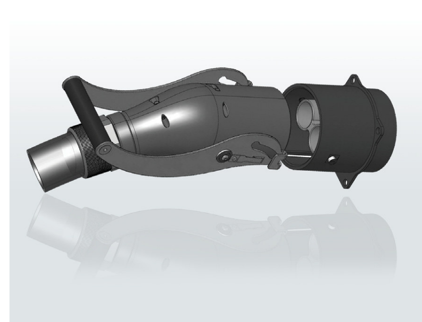
- Maximum output power 3kW to 250kW
- Input voltage 3 phase 480VAC to 600VAC
- Input frequency 50/60Hz
- Output voltage 0 to 600VDC
- Output current 0 to 550ADC
- Power factor .95
- Efficiency >.90%
- Communication CAN
- Vehicle dash communication, Internet communication
- Data logger
- User interface displays
- Payment mechanism (Fig.4)
- Usage meter
- Safety UL pending

Figure 4: User payment mechanism

To meet future vehicle-to-grid (V2G) infrastructure requirements the charger will be capable of bi-directional power flow.

4 Level III Receptacle and Plug

Instead of a fuel-delivery system, both on- and off-board chargers will require a safe, user-friendly delivery system to provide energy to the battery pack. Most EV manufacturers support the SAE J1772 standard for a conductive Level II connector/receptacle or "plug and socket" scheme that supports charge rates of 48A at 220VAC (Fig.5). The US standard includes shock and interlocks protection and is required to support a minimum of 10,000 charge cycles. SAE J1772 Level III plug and socket represents the next



The Fuel Pump of the Future. The EV's energy-delivery system is governed by the SAE and depending on the version of the J1772 standard, can deliver up to 550A of high current in a safe and usable manner.

Figure 5: Off-board charger connector/receptacle

generation of EV charging that provides fast DC energy replenishment by delivering up to 550A at 600VDC of curbside, “on-road” charging. As currents increase, advanced cooling mechanisms in the connector and cable or hose ensure safe and secure thermal management of current delivery. By charging in minutes instead of hours, the higher-current Level III DC scheme contributes to the alleviation of range anxiety and thus further enables the practical, broad-scale adoption of electric vehicles.

Level III chargers are designed to interface with charging coupler standards also being developed by the SAE J1772 group. The proposed Level III 400Amps coupler (Fig.6) will meet all SAE J1772, UL 2202, 2231, 2251 standards:

- 400A charge current rating
- 600VDC voltage rating
- 2 x 11.1mm power pins
- 1 x 8.0mm ground pin
- 4 x 2.4mm signal pins
- Touch proof, scoop proof pins
- Proven 10K cycle durability
- Injection molded shell/insulator

The charging station interfaces with the vehicle’s battery pack battery management system (BMS) through the signal pins (Fig.6). The communication standards are currently under development by the SAE Communications Task Force. The work on J2836 communications protocol is an outgrowth of the original communication standards J2293 used on chargers in mid-1990s. Level III charging has been demonstrated in 2007 and 2008 using a simplified version of this protocol as discussed in section 7.

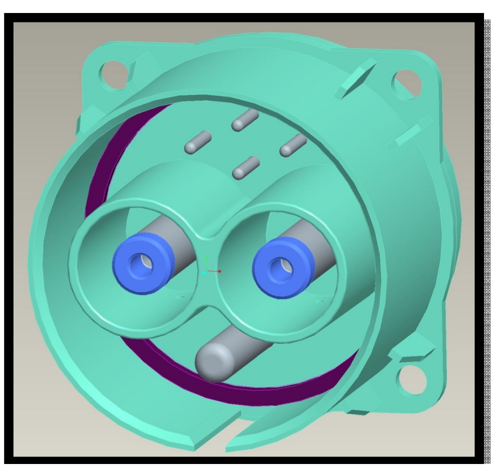


Figure 6: Level III 400Amps coupler

5 Battery Technology Is the Key for Fast Charge Adoption

The factor limiting the success of electric vehicles has been the storage of electrical energy. Batteries have hindered the performance, range and cost of electric cars to a point where they viable for everyday consumer use. However, recent developments in lithium-ion cell technology have shown promising results: the improvements in energy density, capacity and cycle life are allowing fully electric passenger vehicles to reach a new level of performance, where they can compete on the same playing field as their combustion-powered counterparts.

The relation between the minimum recharge time and the range per charge in miles for different battery technology is shown below (Fig.7).

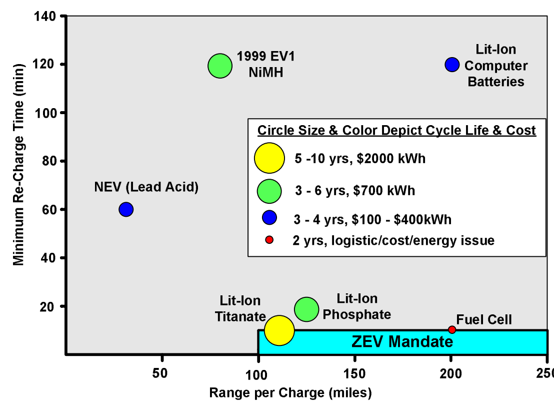


Figure 7: Recharge time and range for EV batteries

Presently the only battery chemistry that allows for safe 10-minute recharge time that does not impact cycle life is based on nano-structured lithium titanate spinel oxide (LTO) electrode materials that replace the anode graphite materials of current Li-Ion batteries.

Altairnano has developed a technology that operates in the high power region (charging) not previously served by other technologies. The relation between specific power and specific energy for various battery chemistries is shown below (Fig.8) [3].

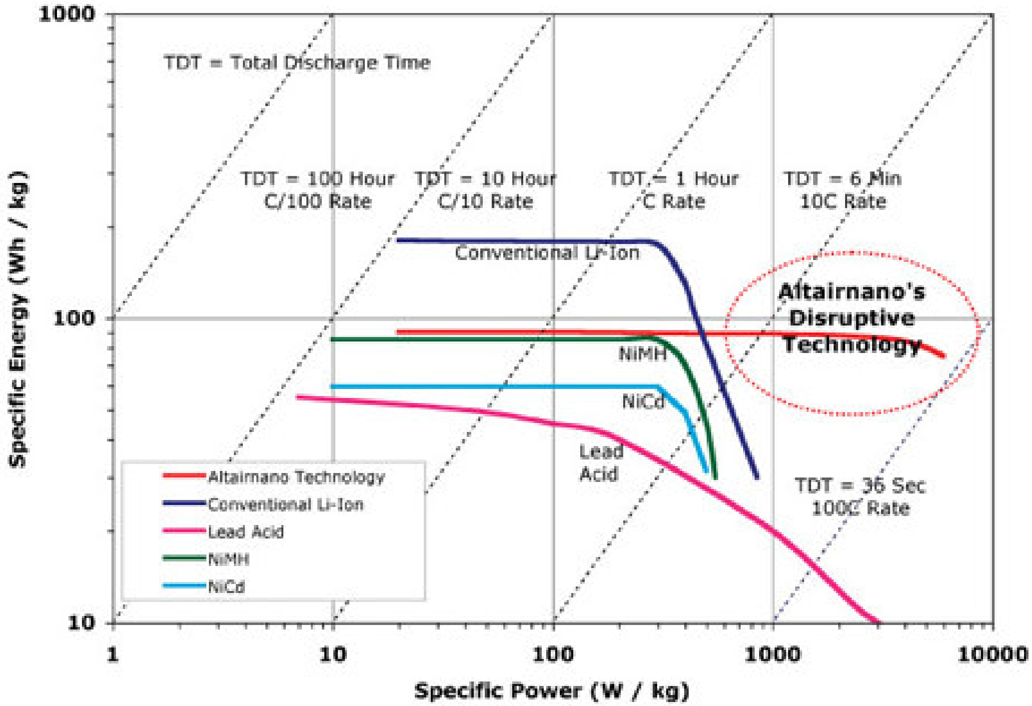


Figure 8: Comparison of the performance of Altairnano's new technology to other battery chemistries [2]

This new chemistry is already manufactured in low volume by Altairnano (ALT). It offers great fast recharge capability up to 6C rate (10 min).
Altairnano's new electrode materials offer an environmentally safe battery with:

- Innovative technology
- Large configuration choices
- No operational safety issues
- Three times the power of existing batteries
- A one-minute recharge
- High cycle life – 10,000 to 15,000 charges vs. 750 for existing batteries
- The capability to operate in extreme temperatures: -22° to 480° Fahrenheit
- Low life-cycle costs

Altairnano Technologies, Toshiba, Ener1 and others are reported to manufacture LTO lithium batteries**.**

Toshiba Corporation recently announced the commercial launch of the SCiB – the Super Charge ion Battery – a fast-charging battery that offers excellent safety and a long-life cycle of over 10 years, even under conditions of constant rapid charging. The safety characteristics of SCiB allow recharge with a current as large as 50 amperes (A), allowing the SCiB Cell and SCiB Standard Module to recharge to 90 percent of full capacity in only five minutes.

Along with its excellent recharging characteristics, the LTO chemistry also exhibits a long cycle life, on the order of 5000-10,000 discharge and recharge cycles, and can operate at very low temperatures. At minus 40 degrees centigrade, the battery can discharge 80 percent of its capacity, against 100 percent in an ambient temperature of 25 degree centigrade [3].

Presently, the most common chemistry used in United States is lithium iron phosphate ($LiFePO_4$), manufactured by A123, Valence and others. Based on new nanoscale materials initially developed at MIT, A123Systems' low impedance nanophosphate electrode technology provides significant performance advantages over alternative high power technologies. The technology's charge rate of 3C will allow for a 20-minute recharge of the EV battery.

Another lithium supplier LG Chem, Ltd., has been named the lithium-ion polymer battery cell supplier for GM's Chevrolet Volt. The Volt, scheduled to be launched in late 2010, will be the first mass-produced extended-range electric vehicle. LG Chem will produce the battery cells, and Compact Power Inc., the North American subsidiary of LG Chem, will build battery packs for Volt development vehicles until GM's battery facility is operational [4].

Electric vehicle battery packs last longer and perform better if they are properly maintained and the battery cells are balanced, or that the pack battery management system actively maintains the cells in a series string at the same approximate voltage, and thus, state of charge (SOC). The parallel strings then tend to self balance. Without cell balancing, the pack voltage cuts out at the highest cell voltage during charge and at the lowest cell voltage during discharge. A pack without proper cell balancing cannot keep the cells from wandering from each other (voltage, SOC). Thus, the pack displays dramatically reduced capacity over time, even when the cells may be perfectly fine.

Cell balancing is important for all lithium chemistries, but is more pronounced for those chemistries with high internal resistance, such as traditional format lithium (computer batteries, for example, use traditional format lithium.) Fast charging also exacerbates cell wandering for packs with battery management systems that do not properly balance cells.

6 EV Charger Infrastructure

Providing EV and PHEV charging infrastructure, including fast charging, will be a long-term activity. In the mid-1990s, 60kW rapid charging systems were developed to enable the adoption of electric vehicles.

These 60kW charging systems became the industry standard for rapid chargers and enabled motorists to charge their electric vehicle in a matter of minutes rather than hours with conventional charging. The chargers used a conductive Level III DC connector developed to charge the EVs being produced to support the 1998 California Air Resources Board Zero Emission Vehicle (ZEV) mandate. Ford and Chrysler EVs were factory upgraded to use the rapid chargers, branded PosiCharge. Many of the chargers were used for fleet services such as airport shuttles and city bus services.

The most ambitious program was implemented by Hawaii Electric Power and the state of Hawaii to provide a network of dozens of the 60 kW fast chargers around the island (Fig.9) of Oahu to support mass use of EVs.

The rapid charging stations comprised UL listed Level III chargers. The chargers included a UL listed level III connector. The communication protocol used for interfacing with the vehicle battery management system was based on J-2293.

Presently the initial markets for the EV chargers are the fleet vehicles for government, municipal and commercial applications. In the United States alone there are 9 million fleet trucks and passenger vehicles. The consumer marker appears to be evolving rapidly with a number of companies planning to introduce electric vehicles by 2010. Eventually, the charger market could include retailers, gas station owners, parking lot operators, malls and alternative energy suppliers.

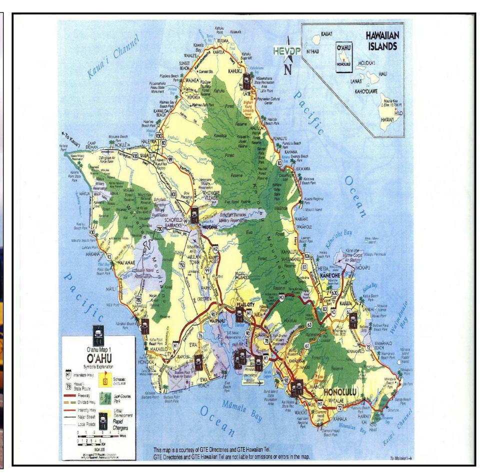


Figure 9: PosiCharge 60 kW Fast Charger supporting electric shuttle fleet

7 EV Charger Demonstrations

AeroVironment, Altairnano, Micro-Vett, SPA and Go Green Holding AS, jointly demonstrated the All-Electric Fiat Doblo to government officials and potential commercial customers in Oslo, Norway. On October 2, 2007 – half-way through a 30-day demonstration – the Micro-Vett Fiat Doblo, a regular size 5-seat station wagon vehicle powered by a custom 18 kWh Altairnano high performance NanoSafe® battery pack, travelled 300 kilometers (186 miles) in an urban delivery circuit. The custom battery pack was fully recharged on that day in less than 10 minutes three separate times using AeroVironment's high voltage, 125kW rated, rapid charging system.

Figure 10: All electric Fiat Doblo

8 Conclusion

This paper provided an overview of the recent activities relative to EV infrastructure. Charging infrastructure, including Level I, II and III chargers, is currently being implemented in many cities across the world in anticipation of the coming wave of EVs and PHEVs. Fast-charging will supplement the Level I and II infrastructure activity around the globe that will enable broad adoption of EVs and PHEVs.

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