Electric Vehicles – Charging Stands & Infrastructure

Mark Clapper
GE Specification Engineer

I. INTRODUCTION

Fueled by environmental concerns, the cost of energy, and the advancements in battery technology, the electric vehicle continues to march toward mainstream society, and along with the march, come the associated concerns about the infrastructure required to support them.

This article will offer some basic insights in the areas of electric vehicle architecture, charging stands, and the associated charging infrastructure.

II. SOME HISTORY TO START[1]

To gain some perspective on the electric vehicle, a brief walk through its history is offered.

Although the exact date is unknown, a Scottish inventor named Robert Anderson developed the first electric carriage in the 1832 – 1839 time frame. Mr. Anderson's carriage was powered by non-rechargeable batteries available at that time.

He was followed by the American, Thomas Davenport who is credited with the first practical EV, a locomotive, back in 1835.

Through the remainder of the 19th century, various inventors and scientists made contributions to this industry including the first lead acid, rechargeable battery in 1859 by French Physicist Gaston Plante' and an American built EV by William Morrison of Des Moines, IA (1891).

It may surprise the reader to know that the first electric taxi in the US hit the streets of New York City in 1897, and that the heyday for EV's in the US was in the year 1900, when 28% of the 4,192 cars produced were electric. The heyday of the EV was short lived though, due in large part to the introduction of the first gasoline powered, mass produced vehicle in 1908; the Henry Ford Model T.

Wind the clock forward 110 years, and the introduction of the Nissan Leaf™ and Chevy Volt™ are upon us. Couple this with global EV charging stand projections of 3 million units by 2015[2] and we find ourselves asking not if, but when the electric vehicle population will develop, and how can we prepare our infrastructure to fuel the new machines.

III. TERMINOLOGY

There are several terms that are widely used to describe electric vehicles. They are listed below for consideration.

<u>Hybrid vehicle</u>[3] A vehicle that uses two or more distinct power sources to propel a vehicle. The term most commonly refers to hybrid electric vehicles (HEV) which combine a combustion engine and one or more electric motors.

<u>PHEV</u>[3] Plug in Hybrid Electric Vehicle. An electric hybrid vehicle with rechargeable batteries that can be restored to a full charge by connecting to an external power source (charging stand).

<u>BEV</u> Battery Electric Vehicle. A vehicle that uses one or more electric motors for propulsion and uses rechargeable batteries as the sole power source.

EV – Electric vehicle. A generic reference often used to describe PHEV and BEV.

EVSE – Electric Vehicle Supply Equipment. Please refer to figure 5.

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IV. BASIC ELECTRICAL COMPONENTS

From an electrical perspective, BEV'S typically contain the following basic components.

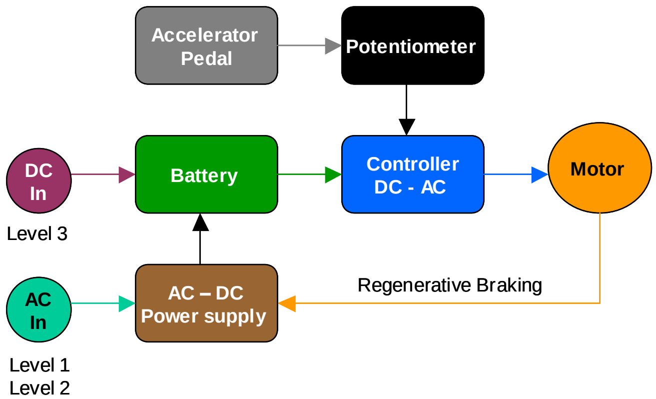

Figure 1 – On vehicle Equipment

- BEV inlet & connector. The inlet is the "on vehicle device" and the connector (plug) is associated with the charging stand. There may be a single AC inlet or a combination of separate AC and DC inlets. The AC inlet is used for Level 1 or 2 charging, while the DC inlet is associated with Level 3 charging. The power inlet is the primary method of recharging the batteries. The combination of the inlet and connector is referred to as the coupler.
- An AC – DC switch mode power supply. The power supply has several functions. It converts AC input power to DC in order to charge the on-vehicle battery pack. It also has intelligence to know what the charge status of the battery is, and may also take into account any thermal information from the battery along with any ventilation requirements.
- A rechargeable battery pack. Stores the energy required to power the vehicle. Lithium Ion batteries are typical.
- A motor or motors to propel the vehicle. Typically AC for on-road vehicles.
- A controller to invert the DC battery supply to AC in order to regulate the frequency and voltage supplied to the motor, and thereby regulate speed. The controller receives its input signal from the accelerator pedal.
- Input signal; an accelerator pedal. Allows the operator to change the power demand to the controller, typically done through a potentiometer
- The ability to regenerate the kinetic energy associated with vehicle movement and braking to recharge the batteries. The recovery of this energy is not enough to completely recharge the batteries, but can help extend the driving range of the vehicle. In combustion engine vehicles this energy is lost as heat through the braking assembly. In BEV's the motor can be used to slow the vehicle; acting as a motor during acceleration and a generator during deceleration.

V. STANDARDS & CODES

There are four key standards related to safety, installation and connecting EVSE to the electric vehicle. They are briefly outlined below for reference purposes.

UL 2594 - Electric Vehicle Supply Equipment. This standard covers EVSE, rated a maximum of 250VAC/ 60 Hz which is intended to provide power to an electric vehicle with an onboard charging unit. The products covered include EV power outlets, EV cord sets, and EV Level 1 & 2 charging stands.

UL 2231 – Personnel Protection Systems for EV Supply Circuits. UL 2231 covers devices and systems intended for use in accordance with the National Electric Code to reduce the risk of electric shock to the user from accessible parts in grounded or isolated circuits for charging EV's.

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NEC Article 625 – Electric Vehicle Charging System. The provisions of this article cover the electrical conductors and equipment external to the EV that connect to a supply of electricity by conductive or inductive means, and the installation of the equipment and devices related to EV charging.

SAE J1772 – Electric Vehicle and PHEV Conductive Charge Coupler. This SAE recommended practice covers the general physical, electrical, functional, and performance requirements to facilitate conductive charging of EV/ PHEV vehicles in North America. This document defines a common EV/ PHEV and supply equipment vehicle conductive charging method including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector.

With some of the fundamentals established, let's explore the charging stands, their features, and end with some installation considerations.

VI. CHARGING STANDS

The charging stand is the primary method to recharge the batteries within the BEV. It has a typical voltage rating of 600 volts and below and in broad terms is responsible for:

a) The safe charging of on the vehicle batteries.
b) Commerce – the ability to facilitate multiple payment options.
c) Communication options – open communication protocols for monitoring and intelligent meters for smart grid interface.
d) Aesthetics, ease of use, the flexibility to support future technology enhancements.

The most common reference used to describe an EV charging stand is its level. The industry recognizes three levels; 1, 2, and 3, with primary differentiator between each level being charging speed, power requirements and cost. Generally speaking, faster charging comes along with increased power requirements and equipment cost.

a) Charging – electrical & time parameters

The typical performance of each level is briefly listed below.

- Level 1, slow charging, 15+ hours
- Level 2, faster charging, 4 – 6 hours
- Level 3, ultra-fast charge, 15 – 30 minutes

The reader should note that the above times describe a charge from a fully depleted battery source. The actual charge time will vary based on the charge level and condition of the batteries. Article 625.14 of the NEC does a nice job of outlining the ratings of charging stand level and they are outlined below.

Level 1 charging

- Power: 120VAC
- Overcurrent device15A or 20A depending on the receptacle.
- Maximum allowable load 12A (1.4 kVA)
- Connection: The NEC permits connection to a common grounded NEMA 5-15R or 5-20R, receptacle (plug & cord).
- Charge time: 15+ hours
- Application: "Opportunity charging"

Level 2 charging

- The NEC notes this as the primary and preferred method of charging at both private and public facilities.
- Power : 240VAC or 208VAC
- Maximum allowable load is 32A (7.7 kVA @ 240V, 6.7kVA @ 208V)

- Minimum overcurrent device: 40A
- Connection: SAE J1172
- Charge time: 4 - 6 hours
- Application: private & public

Level 3

- The NEC likens Level 3 charging to the equivalent of a commercial gasoline dispensing station.
- The cost premium for Level 3 chargers may approach an order of magnitude higher than Level 2.
- Because of individual power supply requirements and available voltage sources, exact voltage and load specifications have not been defined. Refer to individual manufacturers for more information. An example of a Level 3 charger may be a 480V, 400A, 3-phase service.
- Charge time: 15-30 minutes.
- Application: Public

Because Level 2 charging is considered the primary charging method, the balance of this article will focus on this level.

b) Charging – safety related parameters

As previously noted, the charger is tasked with the "safe" charging of the on-vehicle battery system. When one thinks of charging stands, a picture of a person standing in a puddle with an energized power cord comes to mind. To prevent this picture from ending poorly, the aforementioned codes & standards combine to ensure that items such as electrical interlocks, automatic de-energizing of the cable, ventilation interlocks and personnel protection are addressed before allowing electrical power to be applied to the EV.

Electrical interlocks[4] – Level 2 charging stands are required to have an electrical interlock that de-energizes the EV connector and cable whenever it is uncoupled from the vehicle. In other words, power is not supplied to the coupler until positive confirmation that the inlet and connector are properly mated together. Conversely, if they are mated, are under load and become disjointed, power will be automatically removed. This interlock is often to as a "pilot" communication interlock. Please note, this requirement is not present for Level 1 charging.

Automatic De-energization of the cable[4]
Have you ever seen somebody drive off from the gas station with the hose still in the tank? With this scenario in mind, the NEC states that the "EVSE or cable-connector combination must have an automatic means to de-energize the cable conductors and electric vehicle connector when they are exposed to a strain that could result in either cable rupture of separation of the cable from the connector and exposure of live parts." Once again, this requirement is not mandated for plug and cord type chargers (Level 1).

Personnel protection [4] – Both UL 2231 and the NEC outline the requirements for a listed system of personnel protection against electrical shock. Unlike the previous two items, both Level 1 and Level 2 EVSE have to meet this requirement.

Ventilation interlocks [4] – Indoor applications. Hydrogen build up is always a consideration when talking about battery charging. As such, EVSE can be listed or labeled as suitable for charging EV's indoors without ventilation or listed and labeled as suitable for use for charging EV's that require ventilation for indoor charging. EVSE bearing the second label are required to have an interlock in the connector that prevents the EV from being charged until it receives positive confirmation that ventilation is present.

For additional information on these topics, please refer to the standards noted in previous sections.

c) Commerce and Communications

Commerce and communications are two key items that a charging stand needs to accommodate. The owners of the infrastructure need methods to collect a fee for charging stand use, to monitor their infrastructure for service needs, and to allow their clients access to applications that show where EV stands are located, their status, etc.

Commerce

For a publicly accessible EV charging stands, some type of fee collection method will be a necessity.

This means that designers of the EVSE infrastructure will need to become comfortable with the specification and installation of these items. To illustrate this point, please consider that the GE WattStation™ charging stand will support the following payment options:

- Credit card
- Debit card
- SMS payments

Communications

In addition to communications related to commerce, the charging stands will also need to have the options to communicate with the utilities for smart grid metering and with third party applications. The third party applications cover functions that range from identifying stand locations and status, to maintenance and collection services.

To address these needs, the GE WattStation will offer:

- Integral, revenue accurate, smart grid enabled meters.
- Communication protocols will include: Modbus RTU, BacNet, Zigbee, and LonWorks over Ethernet with an option for cellular in the future.

d) Aesthetics and Ease of Use

Since EV charging stands are relatively new and will be in the public eye, some of the frequently asked questions about them include: What do they look like? Do they come in different colors? What are the mounting configurations? And, “What is inside the box?” Unlike the typical electrical installation which is behind closed doors, owners in this operating space are concerned not only with function, but that the design not be obtrusive to the surroundings and be easy to use.

The shape and color offering of a charging stand will vary by manufacturer, but they can typically be categorized into a pedestal, pole or wall mounted product. A picture of a pedestal mounted GE WattStation is shown in Figure 2 for reference.

Figure 2 – GE WattStation

The outside of the stand has a power cord, connector (plug), a cord management system and an interactive display panel used to start the cycle, indicate charge status (% complete), indicate charge status (ready to serve, service needed) and accommodate commerce needs. Refer to Figure 3.

Figure 3 – GE WattStation Interface

The cord management system will encompass the cord, cord storage and connector (plug). A closer look at the connector shows the pilot interface that is used for the electrical & ventilation interlocks along with the automatic de-energizing requirements required by the NEC. Please refer to Figure 4.

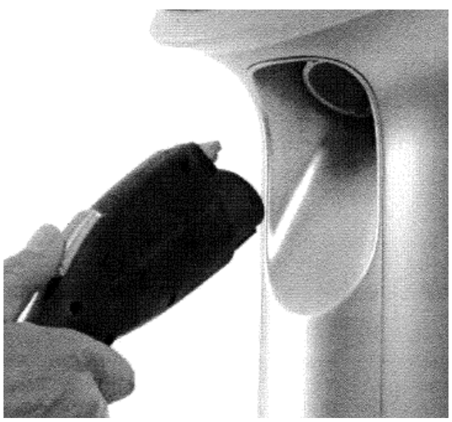

Figure 4 – GE WattStation Cable Management

The electrical equipment housed inside the charging stand, typically includes the contactor, the disconnect, the control boards and the personnel protective device. Depending on the application, there may also be a smart meter and a communications module.

The final topic of conversation pertains to the installation of the EVSE. Article 625 of the NEC provides substantial installation details on this matter, and rather than duplicate that information below, the goal of the closing paragraphs is to quickly note the traditional installation related items and then raise awareness of some new considerations and skill sets that may need to be developed when considering EVSE as a potential revenue stream.

VII. INSTALLATION CONSIDERATIONS

The basic installation considerations associated with EV charging stands and upstream equipment are not unlike those we see every day. Figure 5 illustrates the type of electrical equipment associated with EVSE installation.

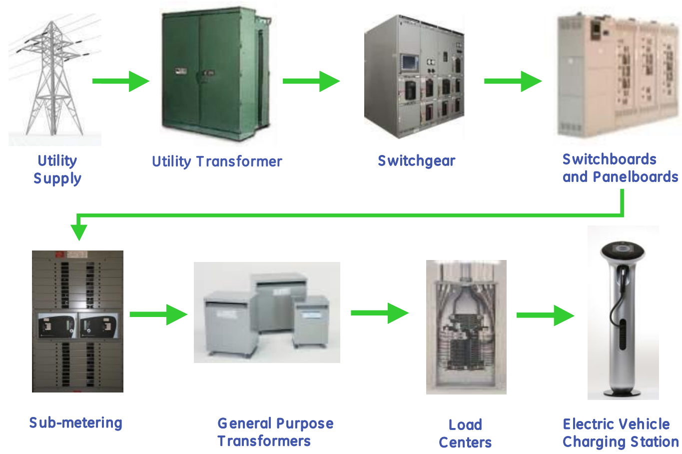

Figure 5 – Typical EVSE Equipment

The governing installation standard for EVSE is Article 625 of the NEC. This article mandates the usual items that pertain to:

- Overcurrent protection – NEC 625.21
- Personnel protection – NEC 625.22, UL 2231
- Cable sizing, type, physical length and mounting height – NEC 625.17.

Outside of the above, there are some non-traditional tasks that may require additional thought, potential code revisions, design time & perhaps some new skill sets. These include:

- An audit of the available kVA capacity in the system. Both from a utility and installed equipment viewpoint. Please recall, a typical Level 2 charging stand is 32A @ 208/240V = 6.6 to 7.6 kVA per stand.
- Harmonics – Since each EV has an "on vehicle" switch mode power supply associated with it (AC – DC), there will be some level of harmonic distortion generated by this device. At present, there is not a large volume of information to quantify the impact and the potential need for mitigation in the upstream equipment. It is mentioned in this article, because the design engineer needs to be aware of the consideration, but the information may emanate from the auto manufacturer rather than the EVSE manufacturer. As installations grow, this is a topic that will require additional study and publicized information.
- Ventilation requirements (indoor). Refer to NEC 625.29D.
- Load balancing – Level 1 and 2 charging stands are single phase load and as such should be balanced in the typical fashion of dispersing them among A-B, B-C and C-A connections.
- Service ratings - In the 2008 NEC, EV's are considered to be continuous loads, which leave no room with regards to reducing upstream capacity needs based on diversification claims. As we gain more experience with these types of installation, perhaps the data will allow the load classifications to change and in turn allow service ratings to be reduced.
- 208V vs. 240V, 32A, single phase charging (Level 2). Assuming a constant current of 32A, does the overall kVA available through the charger have any significant impact on charge time reduction? Should the design engineer lean one direction or another? Is it worth the cost to modify an existing 208V service to 240V? These are questions that will also require additional study as more practical world experience is gained via some of the installations sponsored by grants from the US Department of Energy come into service.
- Communication networks will need to be installed and tested; both hard wired and wireless.
- Commerce – Installers will need to be versed in the installation and testing of commerce applications that accommodate user authentication, multiple payment methods and bill reporting/ generation.
- The physical location of the equipment will most likely be a challenge. Many, if not most of the installations will be to existing parking structures or municipal locations. Perhaps the largest item to contend with will be the routing of power and networking conductors and conduits.
- Resale of electricity. The laws around resale of electricity vary from state to state. New regulations may need to be established to accommodate this action.
- Logistics & flow – Installations may stretch outside of the traditional pedestal or pole mounted applications. Consider an example of a taxicab hub. In this environment the expired battery packs may simply be swapped and the expired batteries placed in recharging racks. A design in this application may mix Level 2 and 3 chargers, and will require that the industrial process/ flow of swapping, moving and recharging the batteries will be mapped out.

The EV dates back some 178 years and it is interesting to see it make a renewed push back into society. The momentum seems to be increasing with new battery plants being constructed, new vehicles being introduced and the US Department of Energy sponsoring pilot EV charging stand installations. This leads to one final thought…the EV's are coming, is our infrastructure ready to accept them?

To view information on the GE WattStation EV charger, please visit

http://www.geindustrial.com/products/static/WattStation/.

VIII. REFERENCES

[1] PBS
http://www.pbs.org/now/shows/223/electric-car-timeline.html

[2] ABI Research 2010

[3] NEC article 625