Getting Ready for Electric Vehicle Charging Stations

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***Abstract* -- Plug-in electric vehicles, i.e. vehicles that use electric motors as the prime means of power will begin to be mass-produced in 2011. The need for electric vehicle charging stations in industrial and commercial facilities is beginning and will grow as the number of plug-in electric vehicles, or PEVs grows. Power system engineers will face challenges when applying the electric vehicle charging stations to their facility power systems. As there are relatively few electric vehicle chargers in use today, the issues and application of this equipment has yet to be seen. The intent of this paper is to make the reader more familiar with electric vehicle charging stations by identifying and discussing the standards to which they are designed and built, and describing the common features and options now available.**

***Index Terms*--Automotive applications, charging stations, electric vehicles,**

I. Nomenclature

While not all of the terms that follow are used in this paper, a familiarity with all of them is beneficial in gaining a complete understanding of electric vehicles and the charging stations that serve them.

Battery Electric Vehicle (BEV) – Vehicles that rely on a battery for their energy. They can either be plugged in to recharge or, in some cases, have their depleted battery exchanged for a charged one. BEVs do not have a fuel tank, tailpipe, or conventional engine, or any on-board means of generating electricity, and typically have a range of somewhere between 60 and 100+ miles.

Grid Enabled Vehicle (GEV) - Vehicles that can plug in to an external power source to recharge. GEVs include BEVs and PHEVs (see below). These vehicles all use electricity to provide at least some of their power and also typically incorporate regenerative braking to recharge the battery with captured energy.

Plug-in Hybrid-Electric Vehicle (PHEV) - Vehicles that have two energy systems. In some PHEVs, the main power source is electricity supplied by a battery, with a gasoline engine working to generate additional electricity when the battery is depleted. These PHEVs typically have a battery-only range of 25-50 miles, with additional range of hundreds of miles using gasoline-generated electricity. Other PHEVs use a conventional gasoline engine as the primary power source, supplemented by a battery that can be recharged by the power grid. These hybrids typically have a pure EV range of 10-15 miles, with extended hybrid driving range of hundreds of miles using gasoline.

Fig. 1. Example of an electric vehicle charging station
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Hybrid-Electric Vehicle (HEV) - Rely on two or more energy systems, most often a battery and a conventional engine. In HEVs, regenerative braking creates electricity to charge a battery, providing a secondary source of power for the vehicle in addition to the conventional engine. These vehicles can only travel a short distance (3-4 miles) on pure battery power and do not plug in to an electricity source.

Internal Combustion Engine (ICE) - The Internal Combustion Engine Vehicle, or ICE, runs on liquid fuels such as gasoline, diesel, ethanol, or biodiesel. The vast majority of vehicles on the road today employ an internal combustion engine.

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Electric Vehicle Supply Equipment (EVSE) - Refers to charging stations and other fixtures outside of the EV that provide the electricity required to charge the vehicle's batteries. EVSE are the "gas pumps" of electric vehicles.

II. Introduction

With the release this year of the Chevrolet Volt and the Nissan Leaf, and the 2012 release of the Tesla Model S, the proliferation of plug-in electric vehicles (PEVs) has started. Given their desirable features of lower operational cost and lower CO_2 emissions, PEVs are likely to be embraced by the driving public and will eventually represent a growing portion of the total light vehicle fleet. Since PEVs are designed to be recharged by connecting with the power grid, some accommodation for them may be desired, if not needed, in industrial and commercial power systems. The desire to install one or more electric vehicle charging stations will probably be due to one of the following factors:

- Provide an incentive to customers who drive PEVs to patronize a business by providing EV charging stations in the customer parking area.
- Benefit employees who drive PEVs by providing the ability for them to recharge their vehicles while they work.
- Demonstrate support for sustainable ("green") development. In addition, LEED credits can be obtained when three percent of the total facility parking area provides alternative-fuel fueling stations, and parking spaces with EV charging stations would obviously satisfy this requirement.

While certain aspects of electric vehicle charging stations are controlled by industry standards, these stations may differ from one model or manufacturer to another by a number of features that may come standard or optional. Understanding the various aspects of electric vehicle charging stations will help the designer to select the best choice for a given application. This paper will discuss electric vehicle charging stations and their application with respect to codes and standards currently in effect in the United States.

There are two classes of charging methods defined by SAE J1772-2010, which is the standard for conductive style connectors to be used on vehicles produced for the United States and Japan. A third method for fast DC charging is currently under development. The classes and their operational characteristics are:

AC Level 1. 120 Vac single phase, 12 A maximum continuous current. This charging level is designed to allow a vehicle to plug into the common 120 Vac receptacle. Recharging a battery at this current can take a significant amount of time, ranging from 12 to 18 hours depending on the energy capacity of the of the battery and its discharge level.

AC Level 2. 208 to 240 Vac single phase, 80 A maximum continuous current. Level 2 chargers are required by the National Electric Code (NEC) Article 625 to be hard-wired into the premises wiring system. This level provides a faster rate of charge than AC Level 1. 30A rated charging stations should reduce the charging time down to a range of four to eight hours.

DC Charging (sometimes referred to as Level 3). This level is intended to recharge the battery in ten to fifteen minutes. While the 2001 revision of SAE J1772 contained DC charging maximum ratings of 600 V and 400 A, those ratings are no longer listed in the 2010 revision. At the time of this writing, the work to define the DC Charging Level connector is in process. Completion and balloting is expected sometime in 2011.

At one time there was also an AC Level 3 method defined by SAE J1772, but it was never implemented. Information concerning AC Level 3 is provided in the appendix of SAE J1772-2010 for reference purposes only.

The Level 1 charger is probably too slow to be beneficial to someone who can plug in only for a limited amount of time. DC chargers are expected to cost 10 to 20 times that of a Level 2 unit, and would probably be too expensive for an owner who isn't using the DC charger as a primary source of revenue. It is not possible to discuss with much certainty the operational characteristics of a DC charging station given that the SAE standard is still in development. In consideration of the above, this paper will limit its scope to Level 2 EV charging stations.

TABLE I
SAE J1772-2010 CHARGING LEVELS

Charge Method	**Electrical Ratings**	
	Voltage	***Max. Current***
AC Level 1	120 Vac single phase	12 A
AC Level 2	208 to 240 Vac, single phase	80 A
DC Charging	Under development	

III. LEVEL 2 EV CHARGING STATIONS

The first thing that must be understood about electric vehicle (EV) charging stations, particularly those defined for applications under SAE J1772 Level 1 and Level 2, is that this equipment is not a charger that makes a direct connection with the vehicle battery, but instead is a connection interface between the vehicle on-board battery charger and a fixed power distribution system. In essence, electric vehicle service equipment, EVSE, is a smart connector that not only connects the vehicle to the grid, but also includes mandatory control and protection features required by SAE and UL standards. They may can have user features that facilitate operation while other features may be included to limit its use to authorized persons.

An EV charging station will typically include following components:

- Overcurrent device for protection against overloads and short circuits.

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- A contactor is used to switch power to the connector, and keep the connector's terminals de-energized when not plugged in.
- A controller interfaces with the vehicle's on-board charging system and provides ground fault protection. The controller may also have some power metering capabilities.
- Displays and indicators on the exterior provide status and alarm information, and guide the user through the operational sequence.
- A cable that connects the charging station to the charging receptacle on the vehicle.
- The conductive connector that plugs into the vehicle.

The mandatory performance and characteristics of the charging stations and their components are regulated by several codes and standards. Foremost among these is SAE J1772 [1][1] as it provides the basic description of the interface. The overall listing standard for EV charging stations is UL 2594 [2][2]. UL 2231 [3] [4] is a complementary standard to UL 2594, containing requirements for personnel protection systems. The other significant UL standards that apply to EV charging stations include:

- UL 62, Flexible Cords and Cables;
- UL 50E, Enclosures for Electrical Equipment, Environmental Considerations;
- UL 2202, Electric Vehicle (EV) Charging System Equipment;
- UL2251, Plugs, Receptacles and Couplers for Electric Vehicles.

Other UL standards for specific components used within the EV charging stations are also applied. These are too numerous to list here. Article 625 of NFPA 70 [5][3], the National Electrical Code, contains requirements for premises wiring systems and installation requirements specific to electric vehicle charging systems.

A. *SAE J1772*

This standard defines the conductive connector, the operational sequence between the charging station and the vehicle's on-board charging equipment, and the control signals that are exchanged between the two.

A typical operational sequence would commence once the user plugs the SAE J1772 connector into his vehicle.

- The electric vehicle charging station detects the EV.
- The EV detects the presence of the SAE J1772 plug and is incapable of being driven away while it remains plugged in.
- The electric vehicle charging station signals to the on-board charging system that it is ready to supply energy. The signal is in the form of a square wave that is driven by an oscillator built into the charging station controller.
- The EV ventilation interlock is checked. Some types of batteries will outgas hydrogen during charging and the build-up of hydrogen gas in indoor applications is a possible explosion risk. Auxiliary ventilation can be provided near the charging station to dissipate the hydrogen. The interlock will identify vehicles that require ventilation for indoor charging. When such vehicles are plugged in, the charging station will supply charging current to the vehicle provided the station has external contacts for turning on the required ventilation equipment. If ventilation is not provided, the charging station will alarm and lock out temporarily. Vehicles that have batteries types that do not outgas will be permitted to charge in both indoor and outdoor locations without additional ventilation.
- The maximum current capacity of the electric vehicle charging station will be signaled to the EV. This is conveyed by controlling the duty cycle of the square wave pilot signal. The duty cycle may also signal that the current capacity will be conveyed using digital communications; however, the process will be terminated if the digital communications is not subsequently established. The EVSE may have the capability to further restrict the charging current based on external signals it receives that reflect supply or premise power limitations. These external signals are not defined by SAE J1772.
- The EV commands the charging station to commence energy flow. The charging station contactor closes and the EV on-board charge controller regulates the current as needed to obtain the proper battery cell voltage and charge levels.

While charging is in process, the safety ground between the charging station and the EV is continuous monitored. The pilot signal is monitored during the process by the EV charge controller and the charge current is adjusted in accordance with the duty cycle. If the duty cycle should vary beyond the tolerances established by the J1772 standard, the EVSE must terminate the process by opening the contactor, turning off the oscillator, and indicating an alarm or error message. While power switches or other operator means for stopping the charge process can be provided, the charging process can be interrupted simply by removing the connector plug from the EV.

B. *UL 2594*

This standard covers EV charging stations that do not require ventilation, with maximum voltage ratings no greater than 250 Vac. Enclosure minimum thickness and strength are among the requirements in this standard.

The maximum length of the cable is limited to 25 feet unless a listed cable management system is provided that controls the cable so that it is not allowed to rest on the floor

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[1] SAE Publications – Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096

[2] Underwriters Laboratories, Inc. Publications – Available from Underwriters Laboratories, Inc., Corporate offices, 333 Pfingsten Road, Northbrook, IL 60062-2096.

[3] National Fire Protection Association Publication – Available from The National Fire Protection Association, Batterymarch Park, Quincy, MA 02269

after use (There is no minimum length of cable that must be provided; the designer should not assume that the maximum length allowed by UL 2594 will be provided and should check to be sure that available products have sufficient cable lengths to reach all the potential plug locations for a given charging station parking space).

Besides electric vehicle charging stations, UL 2594 also covers portable or stationary cord sets. EV cord sets are intended to connect the EV on-board charging system to standard 120 Vac wall receptacles, with personal protection devices connected in between.

C. *UL 2231*

UL 2231 lists requirements for the personnel protection systems required to prevent the undesirable physiological effects that might occur should a user make contact with a live conductor. Such effects include ventricular fibrillation and muscle tetanization which is characterized by let-go, immobilization, and respiratory arrest. UL 2231 is published in two documents that are intended to be used together. UL 2231-1 contains general requirements, while UL 2231-2 provides construction and performance requirements. In addition to basic insulation requirements, UL 2231 requires a “secondary protective mechanism” when the voltage between two conductors exceeds 15 V rms. A number of devices and techniques are listed. Their use can vary somewhat depending on the maximum voltage with respect to ground of the conductors. These devices and techniques include:

- Charging circuit interrupting devices with differential current ratings of either 5 mA or 20 mA.
- A grounding system with a ground monitor/interrupter
- Double insulation
- Reinforced insulation

UL 2231 lists several specific combinations of the above devices and techniques, any of which are considered suitable for the purpose. Most EV charging stations fit into the requirements for designs where the voltage between any two conductors does not exceed 300 V rms and the voltage of any conductor with respect to ground does not exceed 150 V rms. One of the more common permissible combinations will be basic insulation between circuit parts and accessible parts along with a charging circuit interrupting device with a trip setting not greater than 20 mA, combined with a grounding system that connects the accessible parts to the electrical grounding system with a ground monitor/interrupter to interrupt power to all circuit parts when there is no grounding continuity.

D. *Connecting Cable Requirements*

The cable which connects the SAE J1772 connector to the charging station is a specific type required by both UL 2594 and the National Electric Code (NEC) Article 625. Only types EV, EVJ, EVE, EVJE, EVT, or EVJT are permitted. All of these types are intended solely for use as electric vehicle cable. Types EV and EVJ have a thermoset outer covering; types EVE and EVJE have a thermoplastic elastomer outer cover and types EVT and EVJT have a thermoplastic outer cover. The J designates cables that intended for “hard usage” while cable types without the J are intended for “extra hard usage” which is the highest UL 62 classification grade for mechanical serviceability. The cable temperature rating is 60 to 150 °C (140 to 221 °F). These cables have voltage ratings of either 300 V or 600 V. Besides the two power conductors, all cables will have one or more grounding conductors and may contain hybrid data, signal communications, or optical fiber cables.

E. *SAE J1772 Conductive Connector*

At the end of the cable is the SAE J1772 connector which is well defined and standardized. The connector may have one of several current ratings. The most widely available connector at the time of this writing is rated 30 Amperes.

The connector may be stored on the EV charging station in a plug-in style holder. The connector has an angled pistol-grip style handle. A button near the top of the handle allows the plug to be unlatched from both its storage outlet and the inlet connector on the PEV. Thumb pressure on the button unlatches the connector and allows it to be unplugged. The latch mechanism may also include a lock hasp to allow the connector to be locked in place with a padlock and prevent persons other than the user from disconnecting the connector.

F. *EV Charging Station Features and Accessories*

Beyond the mandatory features and characteristics required by the codes and standards that regulate EV charging stations, there are a number of other features, which may be either standard equipment or optional, depending on the manufacturer. These features include visual indicators and displays, as well as the means for granting use of the charging station

Visual indicators, easily viewed from a distance can allow the user or potential users to easily discern the status of the charging station. Through such indicators as colored lights, the following status conditions can be easily conveyed:

- Station active, ac power available
  (this indicator is required by SAE J1772)
- Vehicle connected; not charging
- Charging in progress
- Alarm or Fault

Displays that can show text messages will be a common feature. A suitable display type will allow for easy viewing in a variety of light conditions, for both indoor and outdoor applications. The text messages may include a greeting, instructions for the use of the charging station, and other messages as needed that will convey information to the user.

An EV charging station could be provided that has no means for restricting its use. Such a charging station would then allow free use of the energy to anyone who could connect to it, unless it is otherwise made secure by locating within a structure or behind a fence and a closed locked gate. However, there are means for restricting the use of an EV charging station to a limited number of people and for

Fig. 2. The black module on this EV charging station is an RFID reader
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granting use of the station on a transactional basis. In the first scenario, a Radio Frequency Identification (RFID) reader mounted on the EV charging station can be used to restrict access. RFID readers are capable of detecting small microchips that can be embedded in either ID badges or plastic key cards. The microchip contains information that identifies the holder of the key card. The cards can be configured by a programming unit that is plugged into a personal computer USB port. RFID administration software installed on the computer, working through the programming unit, will activate a key card and determine the class of service for a user (if multiple classes of service are needed). To gain use of a charging station through RFID, the user will pass his card near the RFID reader located on the EV charging station (Figure 2). The RFID unit must be connected via an Ethernet communications network to a PC running the RFID administration software. The software verifies that the user is authorized to use the charging station, and allows the user to proceed. In addition the software will monitor the charging station use, keeping records of the charging time, provide reports on charging station usage and status, and provide records from which the users could be invoiced. The RFID access will be particularly useful to employers who want to give employees who drive PEVs the ability to charge their vehicles while at work, and locate the EV charging stations in publicly accessible parking areas, so no further means of securing the EV charging station is needed. The EV charging station with RFID access could also be used to keep company PEV pool cars charged up while at the work location and not require the EV pool car to be parked in a secure area while it charges.

The enclosures of EV charging stations are designed to accommodate a variety of mounting arrangements and vehicle serving arrangements (Figures 3 and 4). EV chargers that bolt to the ground are commonly referred to as a “pedestal” arrangement. “Single pedestal” refers to charging stations that can serve one vehicle at a time while “double pedestal” charging stations can serve two vehicles simultaneously. Other enclosures commonly provided are “wall mount” for securing to flat surfaces, and “pole mount” for securing to a cylindrical surface, such as an outdoor light standard. Most

Fig. 3. Examples of double and single pedestal enclosure types
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Fig. 4. Example of a wall mount style enclosure
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enclosures will be dual rated for both indoor and outdoor applications.

IV. APPLICATION OF LEVEL 2 EV CHARGING STATIONS

A. Electrical Considerations

EV charging stations in compliance with SAE J1772 and UL 2594 are designed to be connected to either 208 Vac or 240 Vac single phase. The most commonly available models at this writing have a maximum continuous current rating of 30A.

NEC 625.14 requires electric vehicle charging loads to be considered as a continuous load. As a result, conductors serving these loads must have a minimum ampacity of 125% of the load current. This is further reinforced by NEC 625.21 which requires overcurrent protection for EV charging stations to have a minimum rating of 125% of the maximum load current of the EV charging stations. When serving a 30A rated EV charging station from a dedicated branch breaker, a 40A rated breaker and conductor must be applied. The NEC does not recognize any diversity to be taken into account, although papers have been written that indicate that diversity will occur when there are sufficient numbers of EV charging stations [6]. Neither is there any consideration given to alleviate the 125% requirement by applying 100% rated circuit breakers, which could be cost effective on feeders that supply a large number of EV charging stations.

The EV charging station is a significant sized load that will be applied in areas that previously had only very light electrical loads. A parking area may require some minimal power for lighting purposes and the power density of these loads averaged over the surface area of the parking spaces is very little. On the other hand, the load of a Level 2 EV charging station, 30A at 240V, represents a 7.2kVA load. Locating a concentrated number of these among parking spaces will result in power densities in the range of 25 to 50 watts per square foot. Power densities this high are more similar to those of data centers, and previously unheard of in parking areas. The power demands required to serve a concentrated area of several EV charging stations may surprise those designers who attempt it for the first time.

The EVSE is required to have some limited surge voltage withstand capability. They are required to withstand at least twelve surges of minimum 6 kV crest with a follow current of 3,000 A without flashover per UL 2231-2. Tripping or denial of power by the device is permitted provided the device can be reset. The EVSE must also withstand a series of twelve 3 kV x 3,000A surges without flashover and without any tripping or denial of power. These levels of surge severity fall within the test waveforms defined for C62.41 Category A (long branch circuits) and Category B (service equipment that may be located some distance within the building, major feeders, and short branch circuits). They also pertain to Category C (service entrance and other areas pertaining to the external part of building) if the area is known for low lightning activity or little load or capacitor switching (low exposure) [7] [8]. If the EVSE is placed in a location where the surge exposure expected to be higher, appropriately rated surge protective devices (SPDs) should be applied, perhaps at the branch panel that supplies the EVSE. Cascaded SPDs, as recommended in IEEE Std 1100 [9], should be applied where appropriate.

B. Siting Considerations

The location of EV charging stations can involve several considerations. The most obvious of these is to locate the device adjacent to a parking space in close enough proximity that the connecting cable allows the connector to be able to reach the vehicle's charging receptacle when the vehicle is parked properly within the space. Again, consideration should be given not only to the 25 foot maximum cable length required by standards, but also to the available cable lengths that are offered.

It should be recognized that some building codes may require a certain number of EV charging stations to be accessible to drivers who are disabled. As a result, the parking space must be designed to be in compliance with the guidelines associated with the Americans with Disabilities Act (ADA). Additional access space to allow the use of a wheel chair around the vehicle is typically required. Operation of the EV charging station from a wheelchair attitude should be considered.

In all locations the routing of the cables connecting the EVSE to the vehicle should not obstruct pathways subject to heavy foot traffic. The issue here is not only the potential trip hazard but also the possibility of increased cable wear and tear should pedestrians passing through choose to step on the cable itself for any reason.

C. Ventilation

Depending on the type of battery within the vehicle and the location of the EV charging station, supplementary ventilation may be needed to prevent a potentially explosive buildup of hydrogen gas. Some battery types outgas hydrogen during the charging process. In electric vehicles this is limited mainly to sealed lead-acid and Nickel-Metal Hydride (NiMH) batteries. When the EV charging station is located indoors, the risk of a hydrogen buildup increases and supplementary ventilation is required for vehicles containing these types of batteries. NEC 625.29(D) contains specific requirements for the ventilation system including the minimum air flow that must be provided.

However, the newer designs of electric vehicles use lithium ion batteries for energy storage. One of the many desirable characteristics of these batteries is they do not outgas hydrogen and will not require supplementary ventilation when charged indoors. The scope of UL 2594 is specifically written for EVSEs designed to service vehicles that do not require ventilation when charging is performed indoors.

Per the SAE J1772 standard, the EVSE will be able to detect whether a vehicle requires ventilation or not. If it does, the EVSE will alarm and lock out temporarily, and not allow the vehicle to proceed with charging

D. Future Capabilities

The battery within the vehicle represents a potential power source that is an exciting topic of discussion among utility engineers and EVSE manufacturers. This energy source could be very valuable if it could be tapped into during times when brownouts are imminent. SmartGrid capabilities may eventually allow the utility to use the batteries of connected PEVs as a temporary power source. This would be done with some intelligence built into the system. That is, the PEV would have a sufficient charge level on the battery for the vehicle to reach its next destination at the expected time that the vehicle driver normally requires it. Article 625 of the NEC already anticipates such operation. While 625.25 does not allow any backfeed of power from the EVSE on loss of utility power, Article 625.26 permits this when the EVSE is identified and intended as a standby source or electrical power production source. However, when this is the case, the requirements of Articles 702 (Optional Standby Systems) or 705 (Interconnected Electrical Power Production Sources) will apply.

V. CONCLUSIONS

The benefits of PEVs and the need to support drivers of PEVs will stimulate the installation and use of EV charging stations in industrial and commercial power systems.

EV charging stations are well defined by several standards for operational characteristics and personal protection safeguards. Still there are a variety of features and options available depending on the manufacturer or model.

EV charging stations constitute a significant load. In serving a concentrated number of EV charging stations, the distribution system serving these loads will need to have a much higher capacity than previously used in vehicle parking applications.

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