Level 2 +: Economical Fast Charging for EV's

William Korthof
AC Propulsion
441 Borrego Ct
San Dimas, CA 91773
E-mail: wkorthof@acpropulsion.com

Abstract

The Level 2 + standard proposes to combine the cost saving simplicity of conductive Level 2 charge stations with the economy of integrated charging to enable low cost, high utility fast charging infrastructure for electric vehicles. With the quantity and utilization of Electric Vehicles (EVs) increasing, the benefits of faster charging will create a demand for higher charging power. This demand will also be driven by the move toward drive systems that integrate the on-board charging electronics with the propulsion inverter and motor, reducing cost and providing higher power charging. The present SAE standards and coupler designs accommodate high power levels for inductive and off-board conductive charging, yet the conductive standard (J-1772) does not yet provide for AC charging at levels greater than 48 amperes (11.5 kW at 240 VAC). To support fast charging of electric vehicles with high power on-board chargers and standard conductive inlets, AC Propulsion has demonstrated a Level 2-style charging station rated at 19.2 kW and has proposed additions to SAE J-1772 to support on-board AC charging at up to 400 A and 240 VAC.

Level 2 +

The proposed Level 2 + standard enables low cost Electric Vehicle Supply Equipment (EVSE), or charging stations, to deliver high-current AC power to compatible vehicles through the Level 3 contacts of the conductive connector. Avcon conductive coupler contacts are rated at up to 400 A DC and should support the same AC current rating. As proposed, Level 2 + retains full compatibility with vehicles that are equipped for conductive charging under the present J1772 standard. Level 2+ retains Level 2 characteristics, including pilot signal control, vehicle presence detection, ground fault interruption, ground monitoring, Level 2 charging parameters, and load management capability.

Intermediate power Level 2 + charging infrastructure could be installed in many of the same locations as Level 2 chargers and at comparable cost, but with user convenience closer to Level 3 infrastructure. Figure 1 compares charge recovery for Level 3, Level 2, and two Level 2+ systems based on a nominal 30 kWh AC full charge consumption. While Level 2 infrastructure is economical, it only adds 20% to the charge level in one hour. Level 3 charging is substantially faster, but requires expensive infrastructure and compatible vehicles. By contrast, Level 2 + could provide fast charge benefits with costs closer to Level 2 installations.

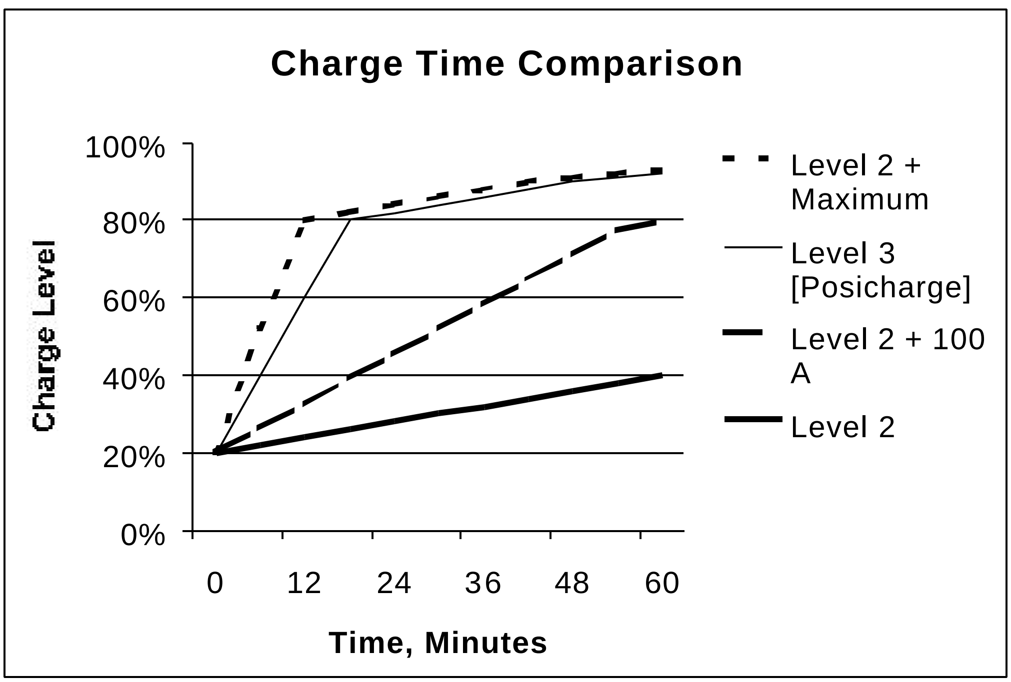

Figure 1. Estimate for Charging Times (30 kWh AC per full charge)

Integrated Charging

Integrated charging systems have been developed for electric vehicles by Ford, GM, Renault, Toyota, and Volkswagen. AC Propulsion drive systems include an integrated charger rated at 20 kW. This system compares favorably in efficiency, weight, cost, and power quality, and also supports several times more power than comparable isolated conductive chargers or inductive charging systems. Integrated charging can take advantage of drive electronics for charging in the following ways:

- Offer charge power up to the continuous rating of the drive system 20-50 kW
- Eliminate redundant power electronics and bulky isolation transformer
- Enable increased charger efficiency levels with a more direct energy path
- Reduce the need for expensive, off-board DC charger
- Enable faster charging without complex vehicle/charge station communication

Compatibility

The Level 2 + design is compatible with existing vehicles using Level 2 on-board chargers as well as those using off-board Level 3 chargers. Level 2 + vehicles can recharge from existing Level 2 charge stations, and Level 2 vehicles can recharge from Level 2 + charge stations at the Level 2 power level (~6 kW).

Level 2 conductive charge stations are designed around a simple, low-voltage pilot signal which provides several safety and control features. A Level 2 + charging station supplying a Level 2 + vehicle would use modified oscillator voltages, a new pulse-width current scale and a new value for Level 2 + charge request. As with conductive Level 2 equipment, battery charging is managed on vehicle; so no digital J1850/J2293 interface is necessary with the charge station. Compatibility of vehicle/ charge station combinations is shown in Figure 2.

Charging Outcomes for Vehicle / Charging Station Combinations

	Charging Station		
Vehicle	**Level 2**	**Level 2 +**	**Level 3**
Level 2	Level 2 (Figure 4)	Level 2 (Figure 6)	No charge
Level 2 +	Level 2 (Figure 8)	Level 2 + (Figure 5)	No charge
Level 2 and 3	Level 2	Level 2 (Figure 7)	Level 3
Level 3	No charge	No charge (Figure 9)	Level 3

Figure 2. Charging combinations. Level 1 is not affected

System Description

The Avcon conductive coupler includes positions for 9 contacts. Contacts 1 and 2 are designated for AC charging current up to 48 A, contacts 3 and 4 are designated for high current DC charging, and contact 5 is chassis ground. Contact 6 is for a control pilot signal, which is used by the charge station to detect the presence of compatible vehicle requesting a charge, and to convey available Level 2 charging power. Pilot signal functions are defined in SAE J1772. Contacts 7, 8, and 9 are for J2293 data communication. The high-current contacts, 3 and 4, may have up to a 400 A rating. Not all Level 2 + EVSE applications would utilize this much current; therefore, a new pilot signal pulse width (PW) scale is proposed to provide a scaled current limit of 0 through 400 amps continuous, compared with the 5-48 amp current limit for Level 2 charging. The proposed high-current scale is:

$$I\ (\text{current limit}) = (600) \times (\text{pulse width}) - (80)$$

Level 2+ charging stations will use modified open circuit pilot voltages of +12/-9vdc, instead of the +12/12vdc in order to distinguish Level 2 and Level 2+ charging modes. A Level 2 + vehicle would use this difference to determine the availability of a high-current AC circuit. A connected vehicle may request either Level 2 or Level 2 + charging. Test point voltages of +9/-3 correspond to a Level 2 + request, where the charging station would use the high-current scale. Other voltage combinations indicate that Level 2 + charge is not requested. The charging station may transition to Level 2 outputs (+12/-12) and the Level 2 pulse-width scale. Subsequent test point voltages of +3/-12, +6/-12, and +9/-12 would represent valid vehicle requests defined in J1772. No resistor value between the pilot and ground can cause a valid charge request, insuring that power is only applied to a properly functioning vehicle.

The Level 2 + confirmation values (+9/-3) imply different resistors for the positive and negative components. The ratio between the positive and negative resistors is approximately 8 to 1, allowing large confirmation tolerance while ensuring that valid confirmations are correctly identified. This also prevents failure in the event of single-component malfunction.

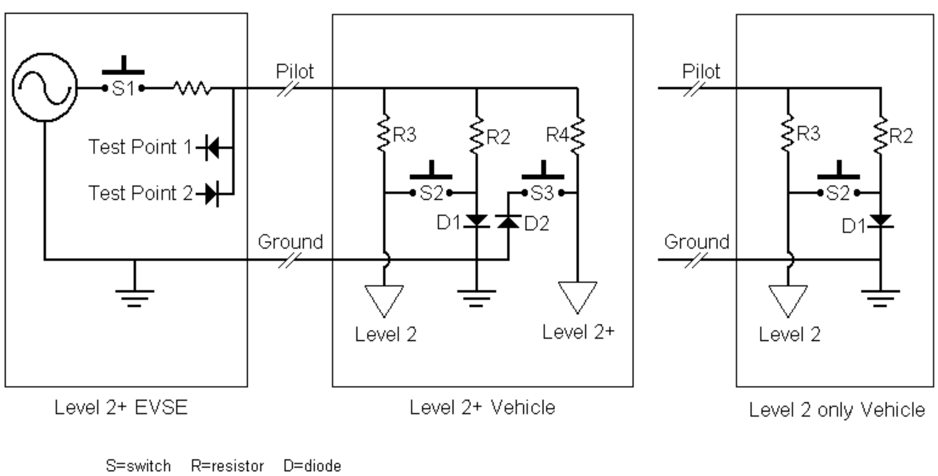

Figure 3. Pilot circuit for Level 2 + EVSE

According to NEC 625-14, EV loads are considered continuous. The maximum allowable charging demand is therefore 80% of the circuit rating. For a charging station on a 100 A circuit, the available capacity is 80 A. When a Level 2 circuit is provided from a Level 2 + charge station, over-current protection would be required (such as local 40 A circuit breaker).

Level 2 + requires additions to SAE J1772. The changes below apply to the existing J1772 tables and are backward compatible with vehicles and charging stations:

Table 3 additions:

State H	Standard Level 2 request
State I	Level 2 + charge request

Table 4 additions:

Level 2 + EVSE (charge station)

Output voltage low—o.c.	-9 V	(+-5%)
Input voltage low—State H	-9 V	(+-5%)
Input voltage low—State I	-3 V	(+-5%)

EV requirements for Level 2 + vehicles

Negative load resistance (R4)	500 Ω	(+-5%)
	(Or 400 Ω if D2 has Vf=0.6)	

Level 2 + charge stations could be built much like Level 2 charge stations, but with several additions. These include some new pilot signal logic functions, a high-current contactor (80 A, 160 A, etc.), and the appropriate high-current vehicle connector. These extra costs are anticipated to be moderate compared to present charging station prices and the benefits of faster charging.

System Operation

A typical Level 2 charging configuration is shown in Figure 4, with the charging station on the left, the coupler in the center, and vehicle components to the right. Contacts 3 and 4 are not used by the charging station but could be wired on the vehicle side for off-board Level 3 DC charging. Digital communication (J-2293) is not required for Level 2 charging.

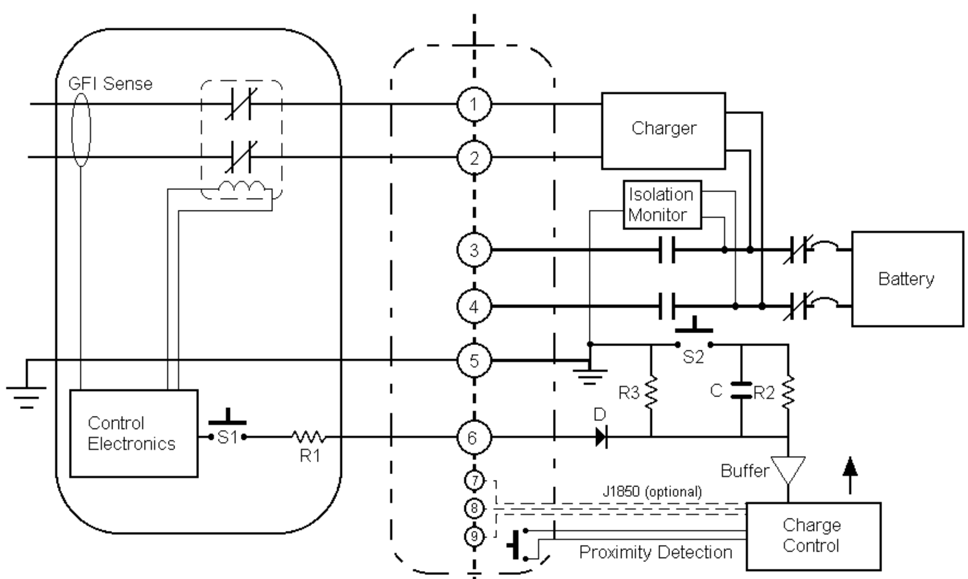

Figure 4. Level 2 Charging Schematic/ Basic System

Figure 5 shows a schematic for the Level 2 + configuration. The charging station includes both low and high current AC circuits to the coupler. The vehicle can accept AC power from the low and high current contacts (1 and 2, or 3 and 4) but not from an off-board (DC) Level 3 charger. Combined Level 3 and Level 2 + compatibility could be provided with additional contactors.

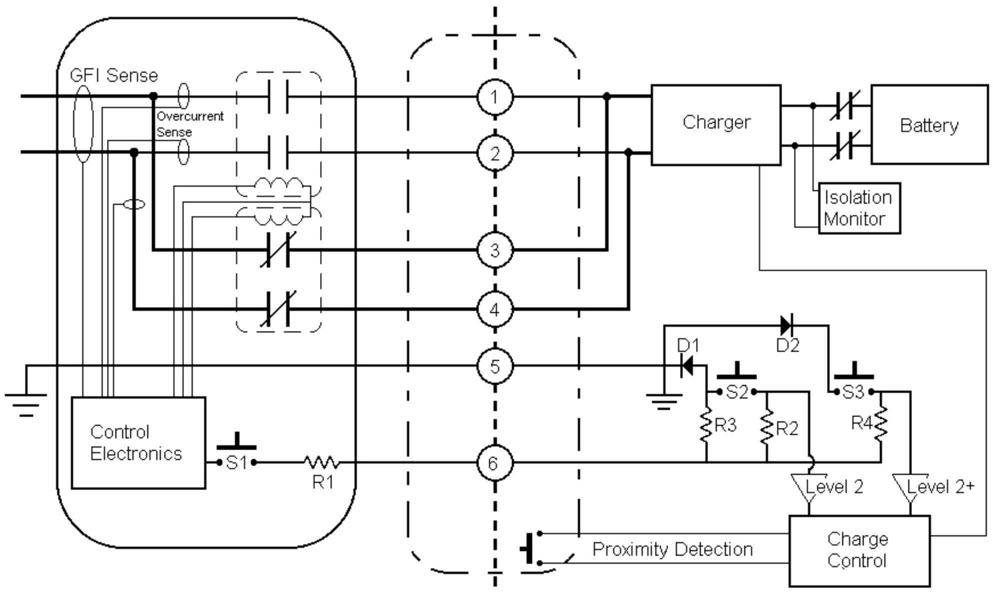

Figure 5. Level 2 + Charging Schematic

To maintain compatibility with Level 2 charging stations, the low-current AC contacts 1 and 2 are wired in parallel with the high-current contacts 3 and 4 respectively, on the vehicle side. The vehicle's charge control can request either Level 2 or Level 2 + AC power and determines the available line current from the pilot signal. This current capacity is encoded on the safety pilot signal by the charging station. The charging station operates only one contactor at a time to prevent an unbalanced parallel current path.

Figure 6 shows the proposed Level 2 + charging station connected to a vehicle equipped for Level 2 charging (e.g. Ford Ranger EV). Available level 2 current is conveyed as pulse width of the pilot signal, following the Level 2 scaling. The vehicle is not equipped to request Level 2 + power; therefore, the charging station only closes the Level 2 contactor. Contacts 3 and 4 remain disconnected because the high-current contactor does not close.

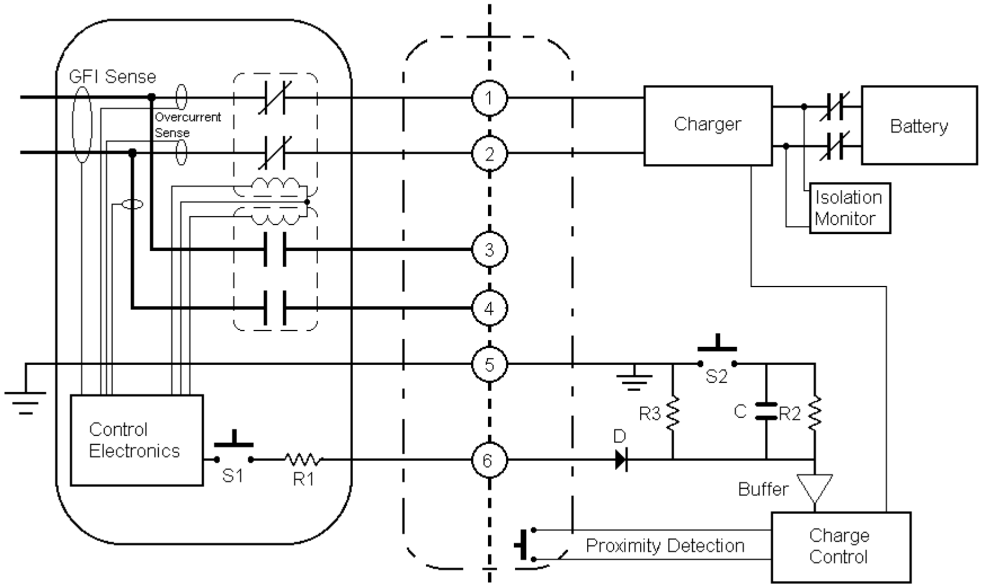

Figure 6. Charging a vehicle configured for Level 2 only.

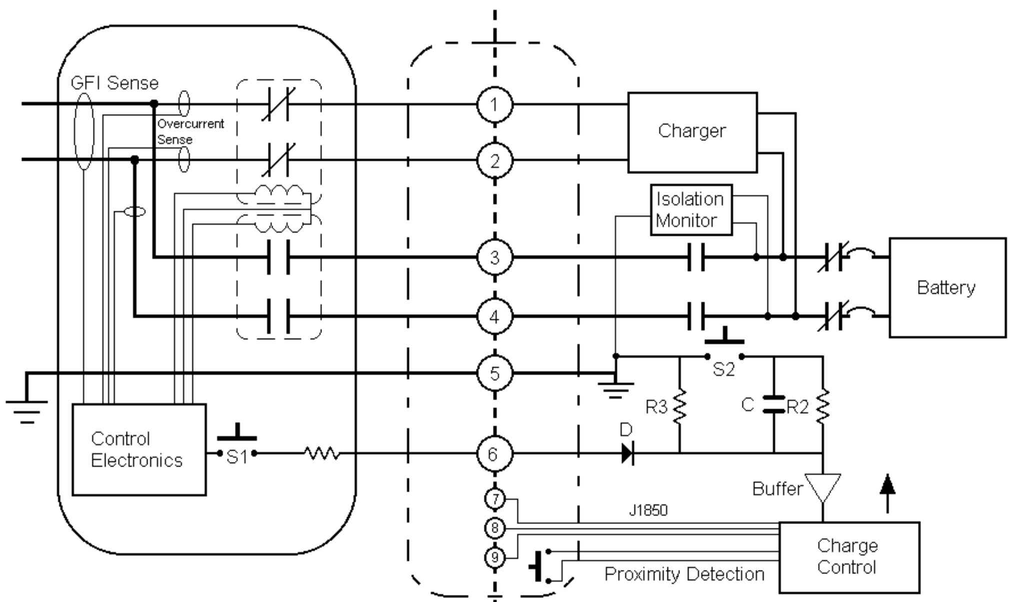

Figure 7. Charging a vehicle configured for Level 2 and Level 3. All contactors for the Level 3 contacts remain open.

Figure 7 shows the Level 2 + charging station charging a vehicle equipped for both regular Level 2 charging and Level 3 off-board DC fast charging. Since the vehicle requests Level 2 power, the charging station will close only the low-current AC contactor. The vehicle will recognize the connection as a standard Level 2 charging station and will charge accordingly.

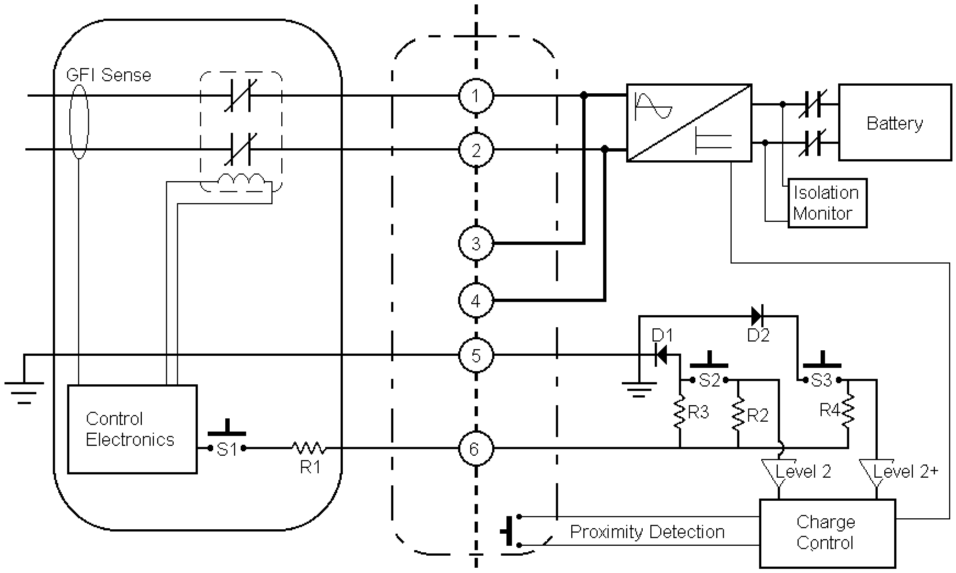

Figure 8. Charging a vehicle configured for Level 2 + from standard Level 2 charging station.

Figure 8 shows how a vehicle equipped for Level 2 + can be charged from a standard Level 2 charging station. In this case, the vehicle determines that only Level 2 power is available and limits charging power based on the Level 2 pilot pulse width scale (J-1772).

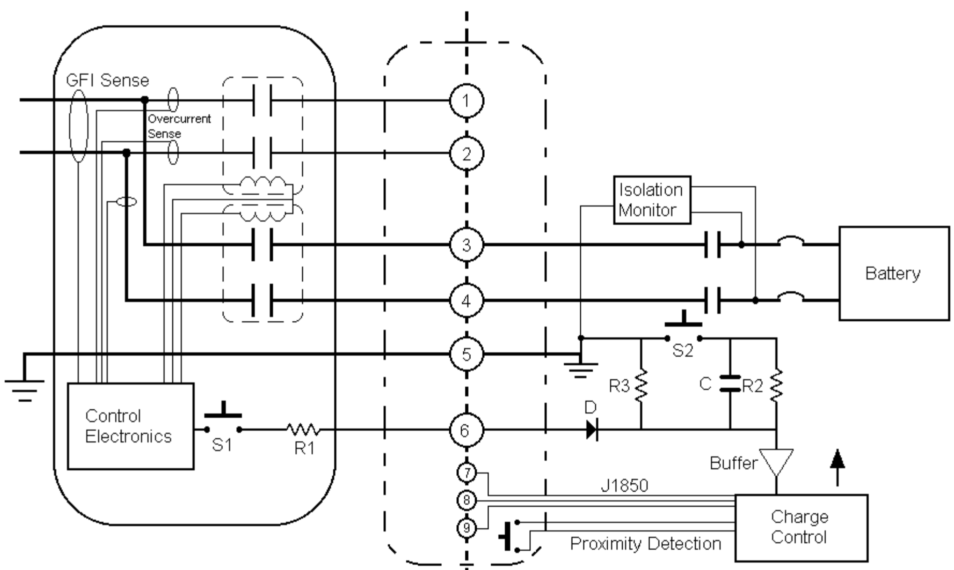

Figure 9. Connecting a Level 3 only vehicle to a Level 2 + charging station. All contactors remain open.

Figure 9 shows the Level 2 + charge station connected to a vehicle capable of Level 3 DC charging only (e.g. Daimler-Chrysler EPIC). In this case, the vehicle cannot use or request AC power because it does not contain the S3 charge request circuit. Both contactor sets on the EVSE remain open. The vehicle will not attempt to charge and its Level 3 contactor will remain open. Level 3 charging requires a pilot signal with 90% pulse width, which is outside the range for Level 2 and Level 2 + charge stations. Level 3 charging also requires J-2293 communication, which is not required for Level 2 +. The high power contacts will remain disconnected from power sources on both sides of the coupler.

Infrastructure Impact

Level 2 + charge stations could be deployed in many of the same locations as existing Level 2 charge stations, including retail outlets, airports, workplace sites, restaurants, transit parking lots, hotels, tourist attractions, and recreation centers. At these locations, more cars could be served by fewer Level 2 + charge stations, offsetting higher installation costs. Faster charging rates would also make Level 2 + systems a more realistic consideration in new locations where drivers would spend much less time, including convenience stores, service stations, fast food outlets, and rest stops. Higher charging rates and reduced equipment cost per kW would make billing systems a more feasible consideration for charge stations.

While Level 3 fast chargers typically require the installation of new electric service panels and dedicated distribution equipment for 480 volt 3 phase power at substantial expense, Level 2 + charge stations use 208 or 240 volt single phase power like Level 2 charge stations. Level 2 + units up to 200 A could be installed in certain locations without substantial extra investment in electrical service panels, wire, and distribution transformers. Many existing Level 2 public charging locations may already have sufficient excess service panel capacity to support 19.2 kW charge stations.

Conclusion

The proposed Level 2 + standard will facilitate faster charging systems for electric vehicles with minimal infrastructure investment and with very low on-vehicle incremental cost. Level 2 + enables high power on-board charging while preserving the standard safety features of J1772 and without affecting the requirements of vehicles and electric vehicle service equipment not using Level 2 +. The proposed standard provides compatibility with Level 2, maximizing the utility of exiting infrastructure and supporting Level 2 vehicles. When electric vehicles can be recharged quickly, range per charge is a diminished concern, and drivers can travel more distance per day. Widely deployed intermediate fast charge infrastructure simultaneously increases range-per-day by hundreds of miles, decreases range anxiety, and mitigates the need for costly advanced batteries. Level 2 + will improve EV marketability by providing cost-effective fast charge capability, and enabling near-term, low-cost battery technologies to meet customer requirements.