



Powering the future of global transportation

Electric vehicle charging

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Introduction

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The rebirth of the electric vehicle occurred around 2009. Over the last decade, the growth of electric mobility has continued to increase on a global scale. Governments around the globe are implementing policies to put more electric vehicles on the road by 2030. Public acceptance and use of electric vehicles are on the rise. All these factors point to a promising and exciting future for electric vehicles.

Today, more than five million electric vehicles are on the road. China remains the largest market, with Europe and the United States next. Over the last year, these numbers have increased significantly in a year to year comparison; a trend that is expected to continue in the coming years¹.

In order to utilize electric vehicles, they must be charged. Today, there are more than five million charge points located around the globe². As the use of electric vehicles continues to increase, the need to charge more vehicles, charge them faster and charge them more conveniently will also be important practical factors.

Over the last decade, we have seen many advances in the area of electric vehicles and electric vehicle charging. Up to now, most of these advances have been related to the

installation of infrastructure and decreasing overall charge times. There were also many lessons learned related to how products would be used, what were considered best practices and what sort of abuse could be expected in the field. During that time, equipment and safety requirements began to stabilize around this technology. But recently, new technologies and new ideas have emerged that push the envelope of existing requirements and create a need to look at electric vehicle charging in a new light.

This paper will look at the existing standards and equipment in the electric vehicle landscape, as well as the trends forming the electric vehicle landscape of the future. This discussion will focus primarily on standards associated with North America and the European Union (EU), with information on other importing markets as applicable.

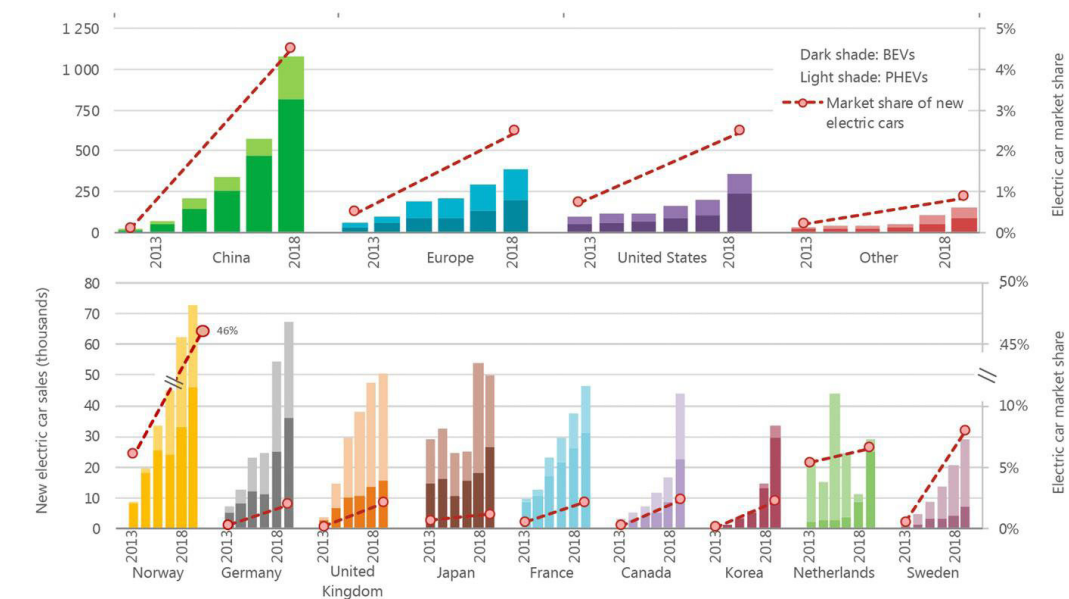


Figure 1 – Global Electric Vehicle Deployments

Source: International Energy Agency

1. <https://www.iea.org/publications/reports/globalevoutlook2019/>
2. <https://www.iea.org/gevo2019/>

Conductive charging

Over the last decade, charging of electrical vehicles has been accomplished through a wired conductive connection to the electric vehicle. Although the types of equipment for accomplishing conductive charging are well established today, it is beneficial to include a brief discussion of conductive charging methods in order to best contrast the new technologies that will be implemented in the near future.

In conductive charging equipment, a physical connection is required to be made by the user in order to transfer power to the vehicle. The connection is made by physically mating a vehicle connector with a vehicle inlet. The connection could be used to deliver alternating current (AC) power that requires an on-board conversion of the voltage to direct current (DC) in order to charge the vehicle battery. The connection to the vehicle could alternatively be used to directly deliver DC power that can be used to charge the vehicle battery without the need for an on-board charger. The off-board equipment with an AC output is generally referred to as electric vehicle supply equipment (EVSE) as it does not charge a battery directly but rather supplies power to the electric vehicle; and the off-board equipment with a DC output is referred to as electric vehicle charging equipment or charger.

Overall, electric vehicle charging is a complex process, with communication protocols, charge event controls, battery management and protection systems that require this type of equipment to be much more sophisticated than traditional general use battery chargers. Additionally, not all conductive charging equipment is the same. Different physical output configurations at the vehicle connector and vehicle inlet will dictate the corresponding communication and charging protocols.

Connecting to an electric vehicle and transferring power, whether AC or DC, requires communication between the off-board equipment and the vehicle in order to provide power safely. The communication protocol is complex and involves many messages to determine that the conductive connection is made, that the vehicle and off-board device can agree on a charging power level based on vehicle battery status and infrastructure limitations, concurrence (sometimes referred to as “handshakes”) to start and stop the charging event and the like. In North America, the approach in the end-product safety standards is to show that the off-board device will mitigate risks or fail safe in the event that the communication from the vehicle is in error. The automotive industry is self-regulating in North America, and the adequacy of the automotive communication system, including efficacy, reliability and the effects over time from abuse, damage, weather, or modification of the vehicle, lies exclusively with them. Because the vehicle is not included or verified as part of the certification evaluation of the off-board charging



equipment, it is not possible to rely on the communication from the vehicle and therefore the off-board device must mitigate the risks or fail in a safe mode. The IEC standards use the same general approach that communication to and from the vehicle cannot be relied on for safety, and that the system must mitigate risk and/or fail safe regardless of what is being communicated from the vehicle.

Protection systems are required to be provided in all off-board equipment in order to protect the user and general public. The main focus addresses protection for the user having direct physical access to parts operating at hazardous voltage, current and/or energy when touching the vehicle and charging equipment during power transfer. The protection systems in North America involve a system that can monitor the vehicle frame, the vehicle connection and the systems of the off-board device in order to shut down the charging event if anything occurs outside normal operational parameters. This is administered through the conductive connection to the electric vehicle. As the off-board equipment can physically touch the electric vehicle during power transfer, the off-board equipment can monitor the vehicle. The protection system in IEC standards can be a single component or a more robust system. The protection system in North American standards and the protection system in the IEC standards are not identical, but the overall conceptual approach is similar.

This baseline will serve as a useful foundation that can be used for the discussion on future technology and the comparison to how this future technology will affect the standards and the safety approach.

The present electric vehicle charging landscape

For the most recent wave of electric vehicle deployment, EVSE made up most, if not all, of the electric vehicle charging infrastructure. The first products to be marketed were provided with the vehicle and used as portable convenience chargers. They were intended to be carried in the vehicle and taken out whenever charging was needed. Once charging was complete, the portable EVSE was intended to be returned to its storage area in the vehicle until it was needed again. They were lower power and could be plugged into any available receptacle so the vehicle could be charged wherever and whenever needed. However, based on their power limitations, these devices took longer to charge a vehicle and were generally considered “overnight” charging.

The next step in charging evolution was to increase power, and wall-mounted, residential charge stations and their public infrastructure began to be installed. These devices were still provided with AC outputs, but the power levels were higher and reduced the charge time to a matter of hours rather than “overnight.”

The demand for DC chargers that would provide DC power at higher power levels and lower charge time compared to AC charge stations emerged. DC charging was a way to decrease range anxiety for drivers by allowing a vehicle to charge in a matter of 1 hour or less so that a driver would not be fearful of being too far from home or their normal charger. This was commonly called “fast charging.” Over time, other designations were also used for fast charging, such as “lightning charge” and “turbocharge.”

AC output devices – electric vehicle supply equipment

EVSE are provided as portable devices, movable devices or fixed devices. Portable devices can be moved with the vehicle and are commonly carried in the vehicle so that a means to charge the vehicle is always present. Movable devices are cord-and-plug connected devices that are mounted on the wall in a garage, car port or other residential location. If the driver sells the vehicle or moves to a new location, the charger can move with the vehicle, but it is not intended to be moved on a regular basis. Fixed devices are typically publicly located in parking lots or workplaces and are fixed in place by bolting them to the pavement, securing them to a post or pedestal and the like. They are also permanently connected to the source of supply. No cord-and-plug connections are used for fixed products. The power levels can be higher in this case compared to cord-and-plug connected devices since the limitations associated with cord-and-plug connected devices do not apply to permanently connected versions of EVSE.

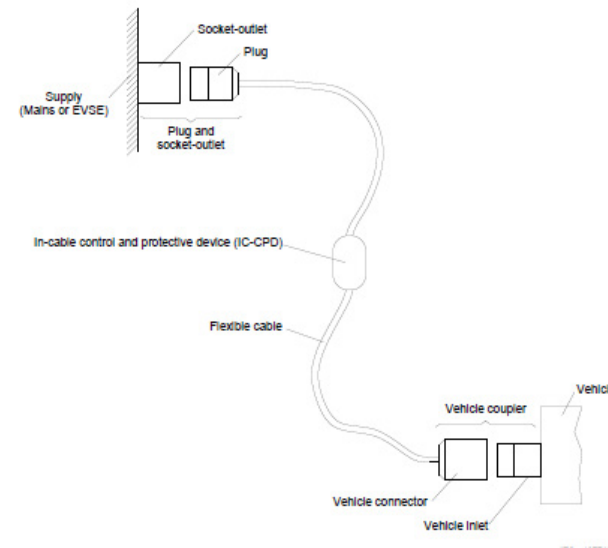
In all cases, the EVSE is essentially a pass-through device. This means that the EVSE provides control and monitoring functions along with communication, but the input and output electrical ratings are generally identical since AC power modification does not occur within the EVSE.

In order to provide AC power to a vehicle, a means to conductively connect the off-board device to the vehicle is required. These connections are not as simple as plugging a device into the wall and they require multiple contacts for power, communication, pilot and ground (earth) connections. In order to accomplish this, special connection configurations are used.

There are four main components that provide for an EVSE conductive connection, shown in Figure 2. This includes the socket outlet, the plug, the vehicle connector and the vehicle inlet. All four of these devices are designated as accessories.

The accessories are used to connect the EVSE to the electric vehicle. Two methods are used to implement the interconnection. In both methods, the cable is permanently connected to the vehicle connector. The difference in the methods occurs at the opposite end of the cable. In one method, the cable is permanently connected to the EVSE; in the other method, the cable ends in a plug that can be connected to a socket-outlet provided on the EVSE. These methods are not interchangeable and depend on the design of the EVSE. In general, North America uses the method in

Figure 2 – EVSE Accessories



Source: IEC 62196-1, Ed. 1.0, dated 2013-04-01

which the cable is permanently connected to the EVSE, and the EU uses the method in which the EVSE is provided with a socket-outlet and the vehicle owner brings the cable with them to connect to the EVSE and the vehicle.

Regardless of the connection method, two main AC configurations apply to North America and the EU in order to provide AC power to a vehicle: the SAE J1772/Type 1 configuration and the Type 2 configuration.

In North America, a single-phase connection to the vehicle is used for all EVSE. The single-phase version of the configuration is referred to as the “J1772” connector in North American standards and as a “Type 1” connector in the IEC standards. The J1772 designation comes from the SAE International Recommended Practice for Electric Vehicle and Plug-In-Hybrid Electric Vehicle Conductive Charging Coupler, SAE J1772, which covers the physical and functional requirements for the accessories. The Type 1 designation comes from IEC standard 62196-2, the Standard for Plugs, Socket-Outlets, vehicle connectors, and vehicle inlets – Conductive charging of electric vehicles – Part 2: Dimensional compatibility and interchangeability requirements for A.C. pin and contact-tube accessories, which includes the same J1772 configuration but designates it differently.

In the EU, a three-phase electrical supply to the vehicle is used for most EVSE, although some single-phase is also used. The configuration typical to the EU is a Type 2 configuration and can be used as three-phase or as single-phase depending on how it is wired. The type 2 configuration is covered in IEC 62196-2. Both configurations are used on EVSE that make use of a similar communication protocol. This communication protocol requires the use of two communication contacts on the connection. Therefore, the J1772/Type 1 configuration is a 5-contact configuration with two power contacts, a ground contact and two communication contacts, shown in Figure 3. The Type 2 configuration is a 7-contact configuration due to the use of three-phase power, and it has three power contacts, a neutral contact, a ground contact and two communication contacts, shown in Figure 4.

For the North American and EU markets, these are the AC configurations that would be used to transfer power conductively to an electric vehicle. Note that other AC configurations exist around the globe, including within China, or may be proprietary to a particular automaker, such as the Tesla connector.

Figure 3 – SAE J1772 / Type 1 Configuration



Figure 4 – Type 2 Configuration



Residential equipment – private access

Residential type equipment is typically used by one person or one family in a residential setting. The product is dedicated to charging one vehicle.

There are two main types of residential devices: the portable EVSE and the wall-mounted, movable type of EVSE.

Today, residential charging is more prominent, and in some locations in the U.S., building codes require new homes to be “residential charging ready” so homeowners can easily have an EVSE installed if they choose to purchase an electric vehicle.

Figure 5 – Portable EVSE



Source: www.teslawallchargers.com

Figure 6 – Wall Mounted, Residential EVSE



Commercial equipment – public access

Public use equipment is typically located in an area that is accessible to any driver in any vehicle. The product is used to charge any vehicle on the market that is provided with a vehicle inlet that matches the configuration of the EVSE output vehicle connector.

Figure 7 – Public Access EVSE





Figure 8 – CCS1 Configuration

DC output devices – chargers

DC output devices are typically fixed in place, permanently connected devices. Although cord connection was always allowed, DC chargers did not make use of this construction. Today's chargers are typically publicly located, such as in parking lots or at car dealerships, and are used to charge a vehicle in the shortest duration possible in order to decrease range anxiety and to make the use of electric vehicles more attractive. The power levels can be quite high, and the industry is continually pushing to increase those levels.

DC chargers take many forms. Some chargers are housed within a single cabinet and others consist of multiple, interconnected cabinets housing different parts of the charger system.

In theory, the output rating of the charger can be any power level, but this is typically controlled by the charging protocol which in turn is tied to what electric vehicles are capable of using. For example, having a 1,500 V output at 600 A is not useful if the vehicles are not capable of using that power level. Today, the maximum voltage contemplated is 600 V DC and the maximum current is 200 A.

Similar to AC connections, in order to provide DC power to a vehicle, a means to conductively connect the off-board device to the vehicle is required. These connections also require multiple contacts for power, communication, pilot and ground (earth) connections. Three main DC configurations apply to North America and the EU in order to provide DC power to a vehicle. These include the combo coupler versions of the AC configurations described above, and the CHAdeMO configuration. The CHAdeMO configuration originated in Japan but is used in North America, the EU and elsewhere as an alternate to the combo coupler configurations, although mainly on electric vehicles produced by Japanese and Korean automakers.

Figure 9 – CCS2 Configuration



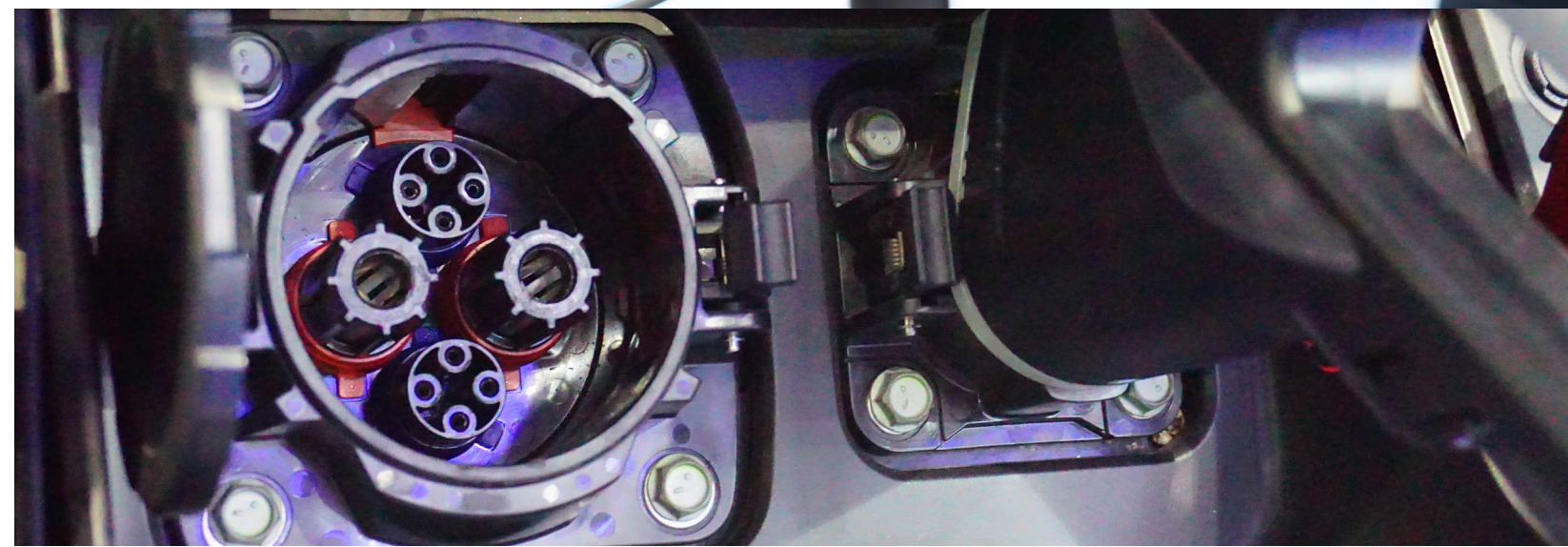
Figure 10 - CHAdeMO Vehicle Connector

In North America, a combo connection is used based on SAE J1772 and expanded to include DC. In the EU, the Type 2 configuration is expanded into a combo connector. These are then designated as CCS1 (SAE J1772 based) or CCS2 (Type 2 based). The concept of this configuration is to have one inlet with the smallest possible footprint on the vehicle that can be charged with an AC connector or a DC connector. These two options make use of the same charging protocol, communication scheme and ground connection as the AC charging connectors described above. Therefore, the only addition is the DC+ and DC- contacts, shown in Figures 8 and 9.

The CHAdeMO configuration uses a more complex communication protocol compared to the combo couplers. This results in a total of six communication contacts, a functional earth contact (for monitoring purposes) and two DC contacts. It is a DC-only configuration, requiring vehicles that utilize CHAdeMO inlets to be provided with an additional AC inlet to allow for AC charging. See Figure 10 for the CHAdeMO connector and Figure 11 for an example of the inlet.



Figure 11 – Example of CHAdeMO inlet with additional AC inlet



Residential equipment – private access

For chargers, there is not much in the way of residential equipment. This is not necessarily prohibited by standards, but the initial push for infrastructure was AC output with an on-board charger, with the use of DC reserved for fast charging. The thought of DC in a residential setting was not specifically considered in the early adoption of electric vehicles. As time goes on, there is some interest in pursuing a more residential application, with lower DC power, to eliminate the need for an on-board charger. However, this has not come to full fruition yet.

Commercial equipment – public access

This equipment is typically located in an area that is accessible to any driver and is used to charge any vehicle on the market that matches the configuration of the charger. These devices are typically fixed in place and are larger in physical size.

Figure 12 – DC Fast Charger



Summary of existing standards

In this section, we will look at the current standards that exist to cover the products noted above. We will provide a high-level summary of each document.

We will look at the standards that exist in North America and the EU based on product type. However, it should be noted that the documents are similar but not identical. The reasons for this stem from the type of certification scheme used in the region, the installation codes and practices used in each region and specific country differences for how products are certified. For the purposes of this discussion, we will consider the documents similar.

Standards in general

In North America, several standards cover safety requirements for EVSE and chargers. In most cases, these documents are harmonized between Canada, the U.S. and Mexico. This means the requirements for the three countries are essentially identical. In the case of the standard for electric vehicle chargers, the documents are not harmonized, but the process to complete the harmonization is underway. At some point in the future, all electric vehicle-related conductive charging standards will be harmonized.

These standards are used for safety certification in North America. They will address the safety of these devices for risk of fire, shock and injury associated with the use and reasonably foreseeable misuse of the product. They will not necessarily cover the design of the product and overall are design agnostic.

Internationally, several standards also cover safety requirements for EVSE and chargers. This paper will discuss the IEC version of the document with the understanding that European Norm (EN) standards may exist that are based on these IEC standards and that individual country differences may also exist within these EN standards. However, this paper will focus on the IEC-level standards without having to consider whether an EN standard exists or to contemplate all the differences between countries. Although this is a simplification of the actual applicability of the IEC standards, it gives us a baseline for discussion.

The CB Scheme applies for all off-board equipment discussed in this paper. The CB scheme is based on evaluation to the IEC base document along with the group and national differences for each destination country within the EU. The standards will cover the fire and shock safety aspects but will also cover some design aspects and performance requirements.



Standards based on product type

EVSE

The North American end-product standard for EVSE is a tri-nationally harmonized document for the U.S., Canada and Mexico. The designation is UL 2594/CSA C22.2 No. 280/NMX-J-677-ANCE with the number designations applying to the U.S., Canada and Mexico respectively. This is the *Standard for Electric Vehicle Supply Equipment*, and it covers portable, movable and fixed EVSE.

In the IEC documents, two standards compete for these product types. IEC 61851-1, the *Standard for Electric Vehicle Conductive Charging System – Part 1: General Requirements*, covers portable, movable and fixed EVSE as well as providing the general requirements for DC chargers. Additionally, IEC 62752, the *Standard for In Cable Control and Protection Devices for Mode 2 Charging of Electric Road Vehicles (IC-CPD)* covers portable and movable, cord-and-plug connected EVSE. The term Mode 2 refers to cord-and-plug connection with AC output in accordance with IEC 61851-1. Both standards claim the product in Figures 5 and 6 under their scope. Currently, the use of both standards is allowed, and which is correct is typically customer driven.

All the documents mentioned are currently published. The North America document is just beginning a revision phase as of the date of this paper. The IEC 61851-1 standard is slated to kick-off its next revision phase at the end of October 2019. IEC 62752 is also beginning preparations for a next revision phase but when that will start is not yet known.

DC chargers

The end-product standard for chargers in the U.S. is UL 2202, the *Standard for Electric Vehicle (EV) Charging System Equipment*. In Canada, the standard is CSA C22.2 No. 107.1, the *Standard for Power Conversion Equipment*. Mexico does not yet have a specific standard. The UL and CSA documents are beginning a revision phase, with Mexico participating, ultimately resulting in a harmonized document. The eventual harmonized document will be tri-nationally harmonized for Canada, the U.S. and Mexico.

In the IEC documents, the main standard is IEC 61851-23, the *Standard for Electric Vehicle Conductive Charging System – Part 23: D.C. Electric Vehicle Charging Stations*. This document is used in conjunction with IEC 61851-1 to cover all aspects of the DC charger. Additionally, IEC 61851-24, the *Standard for Electric Vehicle Conductive Charging System – Part 24: Digital Communication Between a D.C. EV Charging Station and an Electric Vehicle for Control of D.C. Charging* is used to define use cases and messaging for the control of the charging event.

As stated, the U.S., Canada and Mexico are currently harmonizing the document for DC chargers. A revision cycle is underway now for IEC 61851-23 and -24. The anticipated publication date of the new IEC documents is the end of 2020.

Accessories

In North America, the standard is UL 2251/CSA C22.2 No. 282/NMX-J-678-ANCE, the *Standard for Plugs, Receptacles, and Couplers for Electric Vehicles*. This is a tri-nationally harmonized standard with the number designations applying to the U.S., Canada and Mexico respectively. This document covers electric vehicle connectors, electric vehicle inlets, vehicle plugs and vehicle receptacles. This standard is agnostic to the type of configuration and must be capable of covering whatever is available.

In the IEC documents, an overall series of documents cover these accessories. IEC 62196-1, the *Standard for Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets – Conductive Charging of Electric Vehicles – Part 1: General Requirements*, is the document that applies to all accessories. The requirements in Part 1 apply unless they are modified by specific requirements in the other parts. IEC 62196-2 is the *Standard for Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets – Conductive Charging of Electric Vehicles – Part 2: Dimensional Compatibility and Interchangeability Requirements for A.C. Pin and Contact Tube Accessories* and is used to cover AC-rated accessories for specific configurations which include Type 1 and Type 2 as described in this paper. IEC 62196-3 is the *Standard for Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets – Conductive Charging of Electric Vehicles – Part 3: Dimensional Compatibility and Interchangeability Requirements for D.C. and A.C./D.C. Pin and Contact Tube Vehicle Couplers* and is used to cover DC-rated accessories

for specific configurations which include CCS1, CCS2 and CHAdeMO as described in this paper.

Within the part 2 document and the part 3 document are standards sheets. These cover the AC configurations (part 2) and the DC configurations (part 3). The standards are set up such that a standards sheet is required to determine compliance. Therefore, only the configurations shown in the part 2 and 3 documents are suitable for use in accordance with the IEC documents.

Both the North American standard and the IEC series are currently in a revision cycle. Anticipated publication dates for IEC would be end of 2020 and for North America by second quarter of 2021.

Protection systems

In North America, there are two standards that are used together to cover protection systems used in electric vehicle charging. This includes UL 2231-1/CSA C22.2 No.281.1/NMX-J-668-1-ANCE, the *Standard for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits, Part 1: General Requirements*, and UL 2231-2/CSA C22.2 No. 281.2/NMX-J-668-2-ANCE, the *Standard for Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits, Part 2: Particular Requirements for Protection Devices for Use in Charging Systems*. These standards allow for a grounded protection system or an isolated protection system, and both systems are made up of devices and insulation in a manner that can protect the user. These systems are typically embedded into the overall system design and are rarely standalone systems.

In IEC documents, this is handled in a slightly different manner. Most protection is based off a residual current device (RCD) and one is required to be installed in the building wiring or in the product. For EVSE, an RCD is the main protection component and additional devices are not necessarily required. The EVSE standards will call out a Type A or equivalent RCD in accordance with IEC 61008-1, IEC 61009-1, IEC 60947-2 or IEC 62423. For electric vehicle chargers, the entire concept is under discussion in the currently ongoing review cycle of IEC 61851-23 and therefore no specific requirements are published yet to address the protection system.

The need for an RCD is required in both IEC 61851 series and in the IEC 60364-7-722 document for installation of EVSE. In fact, the IEC 60364-7-722 document requires an RCD to be provided in the panel in the building installation. However, for older installations, receptacles may not be provided with an RCD, so portable and wall-mounted, cord-and-plug connected EVSE may not be provided with the protection in the installation. Therefore, IEC 62752, the *Standard for In Cable Control and Protection Devices for Mode 2 Charging of Electric Road Vehicles (IC-CPD)*, was created to address the portable RCD and protection system. As mentioned in the EVSE section above, this standard also duplicates coverage of the overall EVSE which is also covered under IEC 61851-1. However, the protection system requirements only exist in IEC 62752 and are different than what is called out for an RCD in IEC 61851-1.

All these documents are published today. No plan exists for a revision phase to begin this year for UL 2231. The first steps for preparation of the next revision phase of IEC 62752 have begun, but when the actual revision phase will start is not known.

New technology

Now that we have a baseline set for the existing technology, we can look to the future. This involves conductive technologies such as increasing the power limitations for equipment output, using automatic connection means to handle high power connections, providing for a cooling means such as liquid cooling of cables and adjusting current levels to control system temperatures. Each of these advances is a step beyond the existing technology but utilizes the same basis for conductive connection to the vehicle.

Additionally, we will look to three other technologies that are used for charging electric vehicles but are significantly different in overall functionality compared to what exists today. The first technology involves using the vehicle as a source of supply. Although this is still a conductive connection, we are looking to deliver power from the vehicle to an off-board load, which can be accomplished with a bi-directional charger or through specialized equipment. The second new technology involves charging with existing charging equipment but using a power source that is not grid-tied, such as energy storage systems supplied from photovoltaic arrays (PV). The third technology is a method of charging that includes no conductive connection to the vehicle and is designated as wireless power transfer.

These new technologies are new in that standardization is not yet complete. In all cases, some progress in standardization has been made, pilot programs may be in process, the technology may be used successfully in a given market or region, but widespread, commercial application is not yet available. We will discuss the technology from a high level in order to assist with understanding of what is coming in the near future and provide an overview of the standards that are being developed to cover these technologies.

Increased voltage

For today's conductive charging, a lot of consideration is being given to decreasing the charge time as much as possible while producing a product that is safe and user friendly. Part of this consideration is the ease of use of the cable assembly. The user will need to connect the vehicle connector to the vehicle inlet. The ease associated with this action is highly reliant on the cable. The cable must be constructed with appropriately sized conductors for the current involved. More current means a larger diameter cable. As the diameter of the cable increases, the weight of the cable increases, while its flexibility, especially in cold weather, decreases. At some point, a tradeoff is made in which the desired current level results in a cable that is too large, too heavy and so inflexible that the ease of use is nullified. So, if the power level to the vehicle needs to increase in order to reduce charge times, and the current has a ceiling associated with it, the only option is to increase the voltage.

In the past, standards were limited to 600 V AC or DC in North America and 690 V AC/1,000 V DC in IEC. This limitation has been increasing over the past few years, and the new voltage level limits are 1,000 V AC or DC in North America and 1,000 V DC/1,500 V DC in IEC. For electric vehicle charging, this increase in voltage allows for the increase in power while maintaining the existing current levels. However, recreating all the infrastructure pieces, especially vehicle connectors and cable assemblies, was not something that the industry was ready to jump into.

So, rather than starting from scratch, the industry started with the existing constructions. Vehicle connectors and cable make up a cable assembly. The cable assembly will be constructed such that it meets creepage and clearance distances based on its overall highest working voltage. In the past, this was 600 V DC. On top of that, the cable that was connected to the vehicle connector was provided with conductors that were sized according to the expected ampacity associated with the current that would pass through the connector. Once the size of the cable is set, it is connected to the vehicle connector and tested in accordance with the applicable standard. If the current rating was to increase, the wire sizes would need to increase, and this would increase the overall cross-sectional area of the cable. Once the cross-sectional area of the cable increases, modification to the cable opening on the vehicle connector is required. Once that modification occurs, all mechanical testing must be repeated. So, the industry looked for a means to increase the power to the vehicle without requiring a larger cable and modifications to existing connectors.

After some research, some 600 V rated cables were determined to be suitable for 1,000 V without changes. So, when the voltage limit was increased to 1,000 V, the next logical step was to increase the rating of the connector to 1,000 V while using the same cable that was used for the 600 V version. As the cable would not change, all that was required was to make sure the connector creepage and clearance distance were suitable for the higher voltage and that all

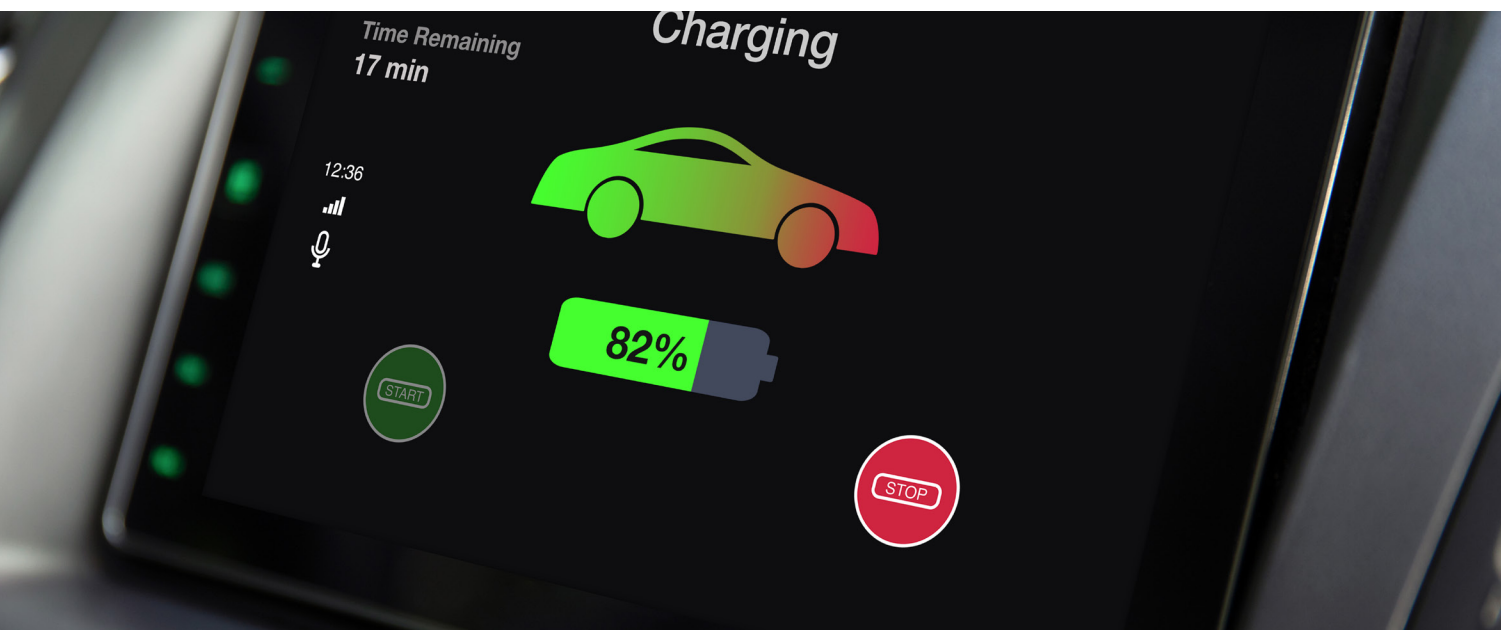
components and materials were suitable for the higher voltage as well.

Some connectors that were already on the market had creepage and clearance distances in excess of what was needed for 600 V and were capable of complying with the 1,000 V values without change. This resulted in vehicle connectors that could be used at 1,000 V with the same current rating as the 600 V models and no changes to the product were necessary.

The increase in voltage does require some modification to the standards, and this is underway now as indicated earlier. In North America, an increase in the scope of the document is needed, and references that refer to voltage levels throughout the documents need to be updated. This revision process is in motion for all the North American standards mentioned in this paper. In the IEC standards, the limit has already been increased or is in the process of being increased at this time.

Lastly, some retesting was required at the new voltage to ensure that compliance was maintained with all testing requirements, and then the industry was ready to move forward.

Now, chargers with output of up to 1,000 V DC are becoming the new norm, and the increased power transfer helps to reduce charge times. The next step is to also increase the current rating, but this will require bigger cables along with the concerns that were described above. So, time will tell if that step is taken at the public charger level.



Automatic connections means

If the concept from the previous section is extended out, higher voltage and higher current will yield higher power to the vehicle. This higher power can reduce charge times overall but can also be used to charge larger vehicles with charge times that are more manageable and attractive. However, as those power levels increase, the means for connection can become bigger, more complex or potentially hazardous for the general public to handle. This is where automatic connection means come into play.

Generally, automatic connection means are used with what is referred to as heavy duty charging and is typically associated with trucks and buses. Trucks and buses make use of larger, more expensive batteries in order to gain the range needed to move the large vehicle throughout the day. The increase in battery size means it takes longer to charge that battery or more power is needed to charge the battery. The use of automatic connection means will eliminate the concerns around large cables that must be manipulated by a person and will mitigate risk associated with the people handling such high-power connections.

A secondary opportunity is also available due to automatic connection. If this is a delivery vehicle, a public bus, or the like, the vehicle will stop at various locations during its daily routine and charging can occur each time the vehicle is stopped. However, it is not beneficial to have the driver plug in at each stop, so the automatic connection means are a good way to address this scenario. These quick charging sessions each time the vehicle is stopped is referred to as “opportunity charging” and is possible because the vehicle is intended to stop at the same location each time. We can look at an electric bus used for public transportation as an example. If an electric bus must complete its entire route multiple times per day on one charge, it is required to have very large batteries to store all the energy needed. If the bus could be charged every time it stops to load and unload passengers, the batteries could be smaller but can accomplish the same task. So, automatic connection means could be installed at bus stops so that the bus can be charged for a few minutes while the bus is stopped. This will extend the range of the bus during the day and allow for smaller, less expensive batteries to be used.

So, standards development began to address automatic connection means. There were many concepts that were included. One of the concepts was to have a bus pull into a charge bay and have it link up with a connection means that was mounted on an overhead rack. This connection means could move a little to each side to compensate for misalignment when the bus pulled in. A second concept

involved a pantograph construction that would lower and contact charging rails on the roof of the bus, shown in Figure 13. A third resulted in connection means extending from the ground under the bus to contact charge rails on the bottom side of the bus. A fourth involved a robotic arm extending and inserting a connector into the inlet on the bus. There are probably more. But any of these means would alleviate the concerns around flexibility of cables, access to high power or ease of use.

Depending on the design, other concerns must be considered that do not exist for manual connections. Does the connection mate properly and only attempt to mate when the vehicle is ready to accept charge? Does the system disconnect correctly so that the vehicle can drive away without damaging the vehicle or the charging equipment? Under conditions of power loss, can the vehicle disconnect from the charging equipment and drive away? Will the connection make and break under load? Can the connection means become live when no vehicle is present? What effect will environmental abuse have on the connection means, both on the vehicle and on the infrastructure? All these issues, and any other issues associated with a given design, must be addressed through electrical safety requirements, but the standards development process would be able to address those concerns.

Some automatic connection means for buses are already in use in Europe and some in the U.S., either as installed systems or pilot programs to test the technology. See Figure 13 as an example of an overhead pantograph system installed in Europe. Not all of the systems are the same, the standardization efforts are reacting to those installed systems, and the lessons learned are based on these installations.

The standards in North America are preparing to address automatic connection means. The SAE International document, the *Recommended Practice for Electric Vehicle Power Transfer System Using Conductive Automated Connection Device*, SAE J3105 is currently in development to cover the physical connector specification, communication and vehicle interface. The charging equipment connected to the connection means would not be all that different from existing technology with the exception of the communication protocol. However, electrical safety will need to be addressed for this connection means as well. It is unknown when publication of the SAE document is expected, but UL is working on an electric safety standard for the overall system now. In IEC standards development, a project team is developing IEC 61851-23-1 at this time. It is not yet published but is expected to be published by December 2020.

Figure 13 – Automatic Connection Means



Active cooling

The next concept moves existing technology to the next level. As was discussed, concerns arise with cable sizes when current is increased. The main concern is that the wires will open and insulation will deteriorate due to the temperatures associated with the higher current passing through the undersized copper conductor. So, what if you could cool the conductors while passing higher current through them?

This is the general idea behind active cooling. Active cooling results in a complex, engineered solution for charging electric vehicles. The main concept is to allow higher power with components that are actively cooled in order to handle it. This involves cooling the electric vehicle connector

and electric vehicle cable on the output of DC chargers. In this way, a smaller cable can be used but a higher current could be passed through the cable. Rather than opening conductors or destroying insulation, the cooling will allow the higher current to flow through the cable without causing these problems.

In order to accomplish this, coolant lines must be passed from the charger through the cable and the connector. The coolant is circulated in order to cool the contacts in the connector and the conductors in the cable. The coolant will also need to be cooled through a radiator system in order to continue its function, so the coolant needs to be brought back to the charger where these radiator systems

are located. However if the coolant fails, the results could be catastrophic. Therefore, continual monitoring of the coolant is needed in order to ensure no hazard develops. This involves monitoring temperatures at the connector contacts as a minimum and monitoring of various parameters associated with the cooling function. The parameters that are monitored are at the discretion of the charger manufacturer. However, a risk assessment can be used to determine of the monitored parameters are sufficient to mitigate risks associated with the cooling system. The charger itself would need to monitor the entire system to maintain operational parameters below specified limits. If any parameter exceeds the limits,

the charger would shut down or reduce output power to its non-cooled limits. The non-cooled limits would be associated with the current rating that could be passed through the output without any outside controls required in order to comply with the requirements in the standard.

The overall operation and functionality is based on manufacturer's design. As each system is an engineered solution, the requirements that are being developed need to address the overall outcomes for compliance rather than what needs to be monitored, how the system is to function and the like. The overall compliance evaluation would require a risk assessment and functional safety review to show reliability of the monitoring means and the components used in the particular system.

In North America, UL 2202 contains requirements outlining how to address liquid cooling from a system level. These requirements are being addressed in the harmonization committee that is currently in process developing the harmonized version of UL 2202 and CSA C22.2 No. 107.1. The result of that effort will be included in the first edition of the harmonized standard. Additionally, the liquid cooled connector is covered by requirements in UL 2251 which are also being vetted through the consensus process now and will be included in the next edition of the harmonized standard.

In IEC, there are also two separate efforts underway to address this topic. IEC 61851-23 is currently in the revision phase and will result in the second edition of that document. Under discussion are the requirements for liquid cooled charging systems. This is expected to be published by the end of 2020. Additionally, there is a new standard part for liquid cooled connectors under IEC 62196-3-1 which is also underway. It is anticipated to be published as a Technical Specification (TS) document by the end of 2019.

Dynamic current control

Similar to active cooling, dynamic current control is another method for charging at higher current while controlling the output to maintain temperatures of the DC charging system within operational limits. However, rather than relying on a cooling means to cool the cable and connector, dynamic current control monitors the temperatures on the system during use. When the system approaches a specific temperature limit, the output current is reduced to a lower level based on the overall size of the cable and the components involved in order to allow the system to maintain temperatures within the operational limit. Overall operation commences by passing a current at a maximum level specified by the manufacturer. During this period, temperatures are monitored at the connector contacts, at a minimum, and the system reacts based on the temperature indications. Higher current is delivered for a short duration, and as temperatures on the contacts approach a preset limit, the current is reduced to a base rating so the charger can continue operation. The base rating is the current that can be passed through the systems without any outside controls to comply with the requirements in the standard. If temperature limits are exceeded, the charger shuts down.

In North America, UL 2202 contains requirements outlining how to address dynamic current control from a system level. These requirements are being addressed in the harmonization committee that is currently in process developing the harmonized version of UL 2202 and CSA 107.1 (clause 16). The result of that effort will be included in the first edition of the harmonized standard. Additionally, connectors used in systems with dynamic current control are covered by requirements in UL 2251 which are also being vetted through the consensus process now and will be included in the next edition of the harmonized standard.

In IEC, there are two efforts underway. These efforts are part of the same standards development as for active cooling. Therefore, IEC 61851-23 is handling the system level and IEC 62196-3-1 is covering the accessories. The date information provided under active cooling will also apply.

Vehicle as a source

Another conductive technology that is under development involves using the vehicle as a source. Using the vehicle as a mobile, distributed energy resource requires some thought behind how this will work, how it can be maintained in a safe manner and how this effects the products that are connected to the vehicle.

There are potentially different levels of requirements based on the intended use case for the system. This includes vehicle-to-load applications, vehicle-to-premise applications and vehicle-to-grid applications; and in each use case either the off-board equipment or the vehicle can contain the inverter. Depending on where the inverter is located, different standards may come into play. Stakeholders include everyone from the vehicle manufacturer to the utility and each step in between.

Vehicle-to-grid involves connecting the vehicle to the grid through an inverter so that the utility can pull power from a vehicle during high demand or the vehicle owner can sell power back to the utility. Vehicles exporting power to the grid at any location and at any time is a safety concern for line workers that may believe a particular circuit is de-energized but is in fact energized by a vehicle. Power quality is also a concern. Power exported to the grid cannot be detrimental to the grid stability or functionality. This use case is being discussed and will require additional work to make sure that it will perform the way it needs to and the way it is intended to with additional considerations for safety.

Vehicle-to-premise involves connecting the vehicle to a home or other premise so that power can be

transferred to the premise during emergency situations. In this use case, the vehicle is acting as a generator and powering a home during power outages or other emergency situations. This use case is a little closer to be commercialized compared to vehicle-to-grid applications but still requires some work.

Vehicle-to-load involves connecting the vehicle to a load off board the vehicle but not tied to the grid or the premise. This could include a device that is powered from the vehicle and provided with receptacles to plug in off-board loads. This may also include receptacles located on-board the vehicle. In either case, the loads that are plugged in could be anything provided with a cord-and-plug connection and could be used at any time.

Some of the issues associated with the development of this technology center on the vehicle acting as a branch circuit in the vehicle-to-load case. Concerns about protection of the loads when the vehicle is acting as a branch circuit are currently being worked out. However, the vehicle does not have any standardized construction or regulation from vehicle to vehicle that would control how that branch circuit will function, including how it protects the appliance and products that are plugged into the vehicle source. Product certification can rely on the circuit breaker in the building installation to protect the product when it is plugged into a traditional branch circuit. If it is plugged into a vehicle, there is no way to guarantee that the equivalent protection is provided or in place since the vehicle is acting as a branch circuit without following the same rules as a branch circuit in the building as outlined

in the National Electrical Code. This may pose potential problems for the equipment that is plugging into the vehicle source. Due to this unknown factor, products that are certified to published standards and requirements, regardless of which region, may no longer have adequate protection when plugged into a vehicle. Therefore, further discussion is needed in this area to ensure that the vehicle will be an equivalent branch circuit when used as a source that is controlled and can be reliably expected to be in place.

In North America, UL has published an outline of investigation that addresses the vehicle-to-premise use case with the inverter in the charging device. This is the *Outline of Investigation for Bi-Directional Electric Vehicle (EV) Charging System Equipment, UL 9741*. Standards development is underway to expand this scope to include other use cases and move this into the consensus process for the U.S.

Additionally, if the inverter is located on the vehicle, SAE International has published SAE J3072, the *Standard for Interconnection Requirements for Onboard, Utility-Interactive Inverter Systems*. This document is also currently being updated and revised.

In the IEC development area, IEC 61851-23 is currently looking at the topic, but it is addressed in an informative annex and is slated for future development after the second edition is published.

Non-grid-tied systems

In order to expand the range of electric vehicles and allow for their use over long distances, infrastructure equipment that can be used for charging these vehicles along the travel route is critical. The concept of having fast charging along main traffic routes requires that sufficient power be delivered to these sites in order to use the infrastructure pieces. However, some of these charging locations may be located where there is no readily available power. One way to provide for charging in these locations would be to use a non-grid-tied system that utilizes energy storage systems to provide power to the charging systems. The energy storage system could be supplied from any source, such as photovoltaics, wind, hydropower and the like. The chargers are interconnected with the energy storage device, and that power is used to charge the electric vehicles. This would allow for electric vehicles to travel greater distances with charging infrastructure along the way.

This technology could also be used for public infrastructure pieces in remote locations, rural areas or anywhere else where energy storage is considered an option.

Although the system may not have a connection to the grid, it is still an electrical installation. Regional codes and rules would apply. Therefore, requirements for the battery, the energy storage system and the charger would need to be met.

In the U.S. and internationally, the same standards would apply for any charger or charge station product as described in previous sections. Regardless of where the input comes from, the charger and

charge station standards cover the infrastructure piece. The energy storage portion of the system is covered in North America by UL 9540, the *Standard for Energy Storage Systems and Equipment*. This is further supplemented by UL 9540A. Internationally, EC 62933-5-1, *Electric Energy Storage (ESS) Systems – Part 5-2: Safety Requirements for Grid Interconnected Energy Storage Systems – Electro-Chemical Based Systems*, is being developed to address these systems, however it will not include the Thermal Runaway Fire Propagation piece.

The batteries used in the energy storage systems are also covered by standards. In North America, this includes UL 1973, the *Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power, and Light Electric Rail (LER) Applications*. Internationally, this includes IEC 62619, *Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Safety requirements for Secondary Lithium Cells and Batteries for Use in Industrial Applications*. In addition to this standard, two other standards are in development and, once published, will cover this battery type and use specifically. This includes IEC 63056, *Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Safety requirements for Secondary Lithium Cells and Batteries for Use in Electrical Energy Storage Systems*, and IEC 62485-5, *Safety Requirements for Secondary Batteries and Battery Installations – Part 5: Safe Operation of Stationary Lithium-Ion Batteries*.

The technology around these system types is increasingly becoming an important discussion

topic and systems are nearing commercialization at scale. These charging systems will go a long way to allowing for long distance travel of electrical vehicles and the systems can be installed wherever they may be needed. This will provide the driver with peace of mind since the charging stations might ultimately become as prevalent as gasoline/petrol stations for legacy automobiles.

Wireless power transfer

As an alternative to conductive charging, work is also being done on the development of wireless power transfer. This is a method of transferring power to an electric vehicle through an inductive connection that does not require physical contact or wires. The technology is billed as a replacement of conductive charging. The driver simply needs to park in the proper location for the wireless system and walk away. There are no potentially dirty, wet or broken connectors to handle.

Additionally, this technology can be used for opportunistic charging which would allow a vehicle to charge whenever it is stopped. This could potentially involve opportunity charging at stop lights, drive throughs or toll booths. For service vehicles, such as buses and delivery trucks, this opportunity charging could take the form of specialized parking or stopping locations that allow the vehicle to charge while it is stopped at bus stops, delivery locations and the like. Taking it a step further, the concept of dynamic wireless power transfer allows the vehicle to travel over a specialized path that will recharge the vehicle as it drives along the road.

The overall technology works through an inductive connection between two coils, with one located on the ground and one located on the vehicle. The off-board system energizes the ground coil from a high frequency source, and the vehicle coil will have an induced current from the inductive coupling between coils.

Many standards are in development activity around this technology. In North America, UL is developing requirements for the U.S. under UL 2750, the *Standard for Wireless Power Transfer Equipment*. For Canada, harmonization with IEC 61980

series is expected in the future. SAE International has published SAE J2954, the *Recommended Practice for Wireless Power Transfer for Light-Duty Plug in/Electric Vehicles and Alignment Methodology*, and efforts have been made by SAE and UL to coordinate the requirements in the two standards. Internationally, IEC 61980-1, the *Standard for Electric Vehicle Wireless Power Transfer (WPT) Systems – Part 1: General requirements*, IEC TS 61980-2, the *Technical Specification for Electric Vehicle Wireless Power Transfer (WPT) Systems – Part 2: Specific Requirements for Communication Between Electric Road Vehicle (EV) and Infrastructure*, and IEC TS 61980-3, the *Technical Specification for Electric Vehicle Wireless Power Transfer (WPT) Systems – Part 3: Specific Requirements for the Magnetic Field Wireless Power Transfer Systems*, have all been published, with parts 2 and 3 as technical specifications as indicated.

The UL 2750 document covers the electrical and system safety of the off-board equipment up to and including the coil on the vehicle. SAE J2954 covers the system on board the vehicle and addresses alignment when parking and interoperability of the overall system. UL and SAE International have a signed Memorandum of Understanding (MOU) to develop our two documents in conjunction with one another in order to avoid gaps and foster a harmonized set of requirements and avoid contradictions.

Many design aspects remain to be worked through, and the technology has been in the standards development phase for nearly eight years. Some pilot programs are in place and some after-market products and some developed systems are getting close to being available on cars.

The design aspects relate to safety, interoperability and functionality. Safety of the overall system involves traditional electrical safety, but in the case of wireless power transfer, the consideration of protection from exposure to the hazardous magnetic field under the vehicle must also be considered. Exposure to this field must be prevented. Systems that are part of the vehicle and/or part of the off-board system are used to detect metallic and organic material in the field and cause the power transfer to shut down. These systems are referred to as foreign object detection for metallic objects and living object detection for organic objects.

Design aspects related to interoperability involve insuring that all vehicles can charge at any charge station. Since there is no physical connection, the driver assumes the charge event has begun and the technology will suffer if it does not work reliably every time. A lot of attention has been paid to this design aspect in order to get the technology right the first time.

For design aspects around functionality, communication between the vehicle and the off-board equipment needs to be addressed. Unlike conductive charging in which the off-board equipment can monitor the vehicle during the charging event, for wireless power transfer there is no method to monitor the vehicle except through communication from the vehicle. The vehicle must monitor itself and communicate correctly and reliably to the off-board system to control the charge event parameters.

This significant effort has taken time to move forward through the standards development processes. As the standardization process gets closer to completion, the technology and its commercial viability is becoming imminent.



Conclusion

Many significant developments have taken place in the area of electric vehicle charging since the initiation of the current generation of technology in 2009. As we move forward, demands from the user community and new technological solutions are pushing the infrastructure to do more and do it faster than before. This evolution leads to new developments and the need for new and innovative thinking, especially for standards and safety requirements. Safety is a foundational element of any successful and sustainable technological deployment and must continue to be actively addressed to support the emerging needs. Standards comprise a critical element of codifying which risks we agree to mitigate and which elements of risk will be accepted. This establishes a solid threshold for both consistent approaches on issues such as safety and morphologies and responsible innovation to differentiate in the market with technological advancements. These factors will support the expanded use of electric vehicles, powering the future of our global transportation systems.

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