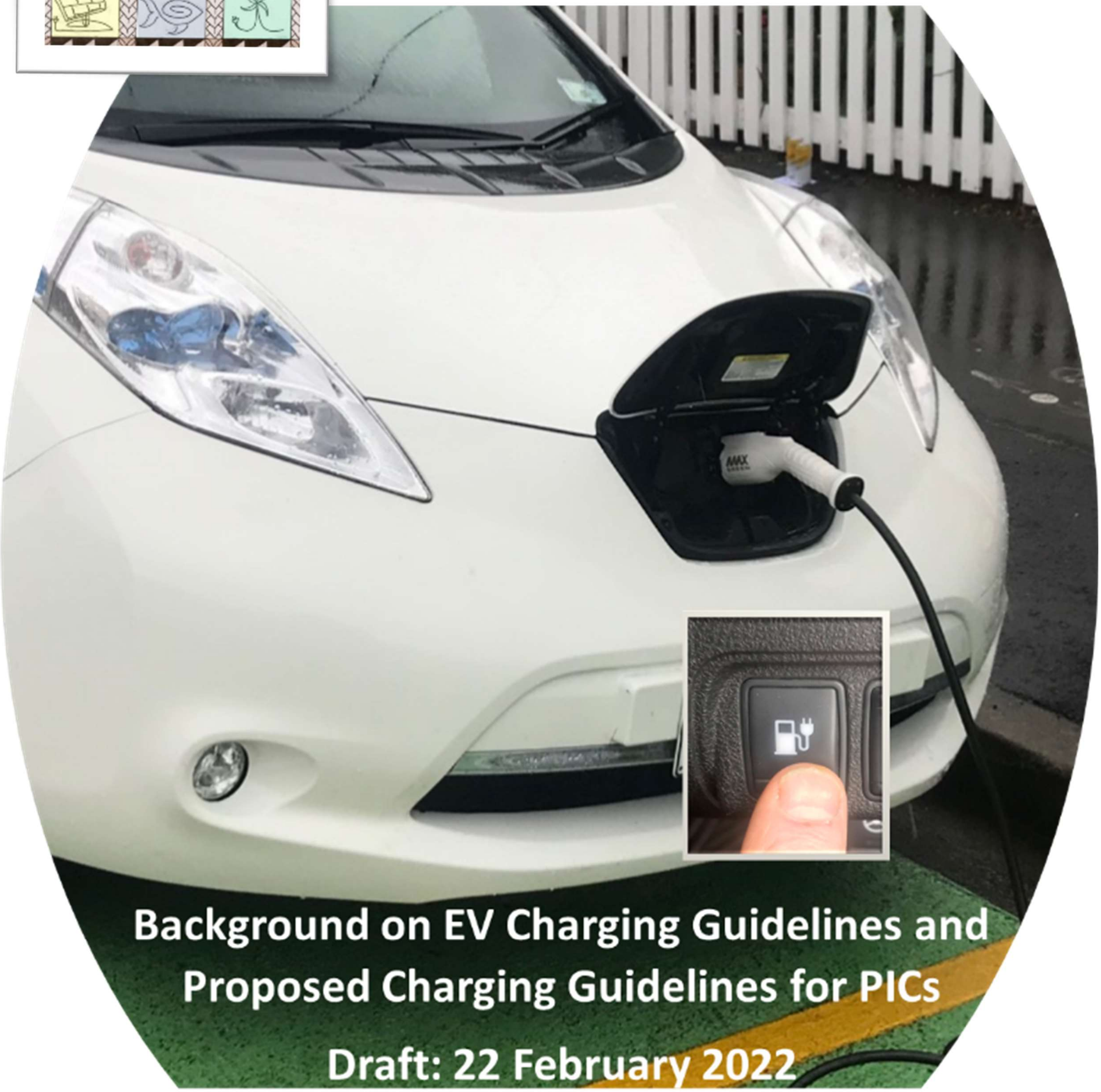

Background on EV Charging Guidelines and Proposed Charging Guidelines for PICs

Draft: 22 February 2022

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Contents

Glossary:

a.c.	Alternating current RCD Residual current device
d.c.	Direct current
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
GFCI	Ground fault circuit interrupter
GFI	Ground fault interrupter
IC-CPD	In-cord control and protection device
RCCB	Residual current circuit breaker
RDC-DD	Residual direct current detecting device
RFID	Radio frequency identification device

1. Introduction

Many people are new to the business of charging an electric vehicle (EV). But while it is new, it is not difficult, and it is very safe if charging equipment, also known as electric vehicle supply equipment (EVSE), is installed and used correctly. The correct use of EVSE extends to ensuring proper supply of electricity to the EVSE, and where electricity is drawn from socket outlets, includes knowing which outlets can be used safely to plug in EV charging equipment, and also knowing the level of protection that there should be on the electricity supply to those socket outlets.

These guidelines are intended to give the reader a base understanding of the principles of charging electric vehicles, in the expectation that it will become as familiar as using any other common domestic appliance.

Besides a general background on electricity supply systems and types of EVSE, there is also some detail aimed at those involved in the design, selection of EVSE, and more complex installations (that is, those that require more than merely plugging a portable changing cable into a domestic-type electrical outlet). This includes the identification of standards with which EVSE should comply. Those entrusted with ensuring these standards are met — importers and installers — can be considered gatekeepers in this respect. Installers (likely to be licensed electricians) are obliged to see that the equipment they install meets the various requirements (and that the installation also meets the national wiring rules and regulations and others). Importers must ensure that the charging equipment entering the country meets the required standards, which may mean that some EVSE imported with used EVs will be excluded, as sometimes it is designed and built for use with different electricity supply voltages or frequencies than in use in PICs.

Note that these guidelines are at a draft stage, as they require checking with numerous local stakeholders to ensure they are fit for various local situations. As an example, electricity supply may be through a low-power connection at certain remote locations with the risk that the power supply circuits will get stressed when used for charging and this may require additional arrangements to ensure that charging can be done safety. The way in which earth circuits are provided can also differ from location to location, and this may require careful consideration, given the important safety function that the earth circuit provides. Input from local stakeholders is expected to provide the necessary calibration of these guidelines to such local variations – and will form an important component of developing these guidelines.

2. Background on EV Charging:

2.1. Different Charging Modes

When purchased, electric vehicles are often provided with a portable charging cable allowing an EV to be charged from a socket outlet connected to a mains supply of electricity. Examples of such portable charging cables are provided in Figure 1.

8 Amp IC-CPD with Domestic Plug

6-16 Amp IC-CPD with 3P Industrial Plug

Figure 1: Examples of Portable Charging Cables, the Charging Cable on the Left Often Supplied with an Electric Vehicle on Purchase.

This charging arrangement is depicted at a more detailed level in Figure 1, beginning with the supply of electricity at a wall socket outlet. We will look into the supply of electricity to the socket outlet later.

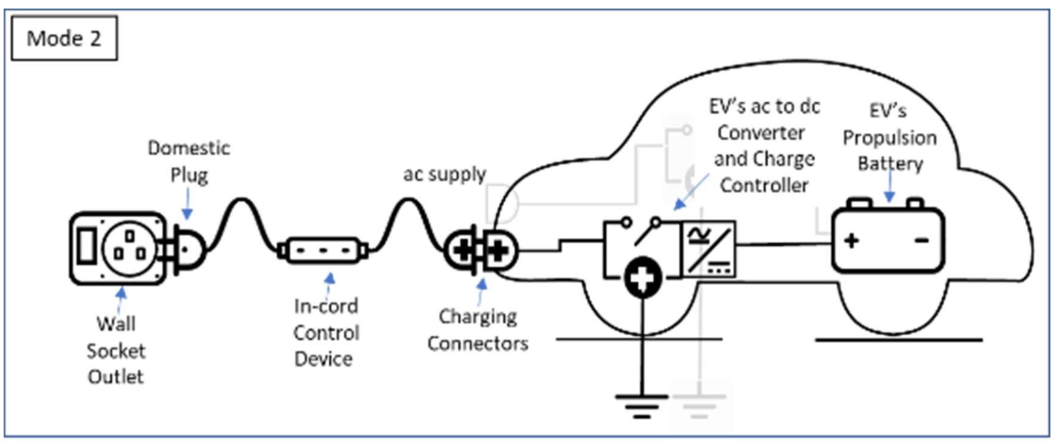

Figure 2: Schematic of Mode 2 Charging (same as for Figure 1, but without the electricity supply to the socket outlet).

This arrangement, where a portable unit which contains an 'in-cord control and protection device' (IC-CPD, sometimes referred to as the 'brick') is plugged into a socket outlet, is termed 'Mode 2' charging. Convention uses four different modes of charging: Mode 2 as depicted above, and Modes 1, 3 and 4 as depicted in Figures 3, 4 and 6 respectively. The main electrical circuit components are common across these but the position of some of them differ. For example, Modes 1, 2 and 3 concern alternating current (ac) charging – where an ac supply is provided to the EV and a converter onboard the EV converts that supply into the direct current (dc) required to charge the propulsion battery (batteries are dc devices). On the other hand, Mode 4 concerns dc charging where the ac to dc charger is off-board the EV and the EV is provided a dc supply for charging (and this removes the weight and size limits of the converter enabling much larger converters to be used, and much higher charge rates to be achieved). And Modes 1 and 2 use socket outlets and are plugged in to use whereas Modes 3 and 4 are permanently wired, with inherent added safety because of this – there are no slip-fit connections that could compromise the flow of electricity, including to the safety of the earth circuit.

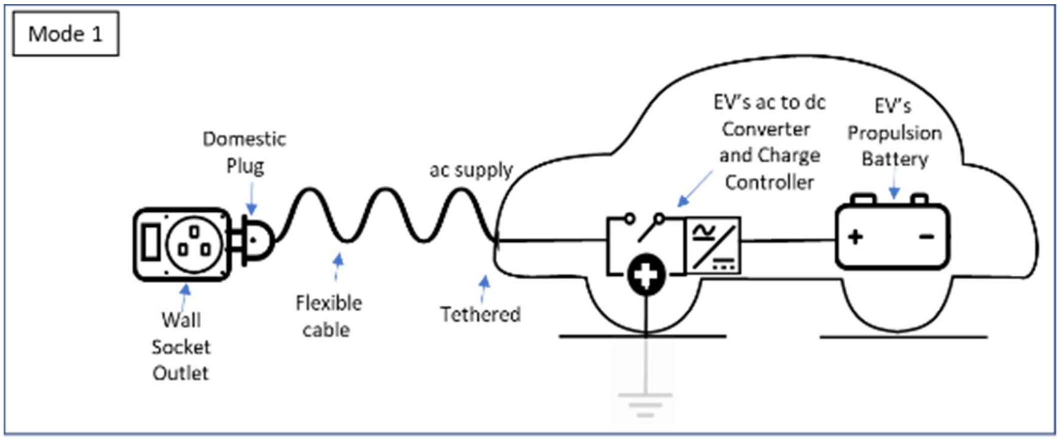

Figure 3: Schematic of Mode 1 Charging.

Note that Mode 1 does not usually have the off-board vehicle pilot control system that the IC-CPD of Mode 2 charging provides and is less safe as a result – reason for why Mode 1 charging is not permitted in some jurisdictions.

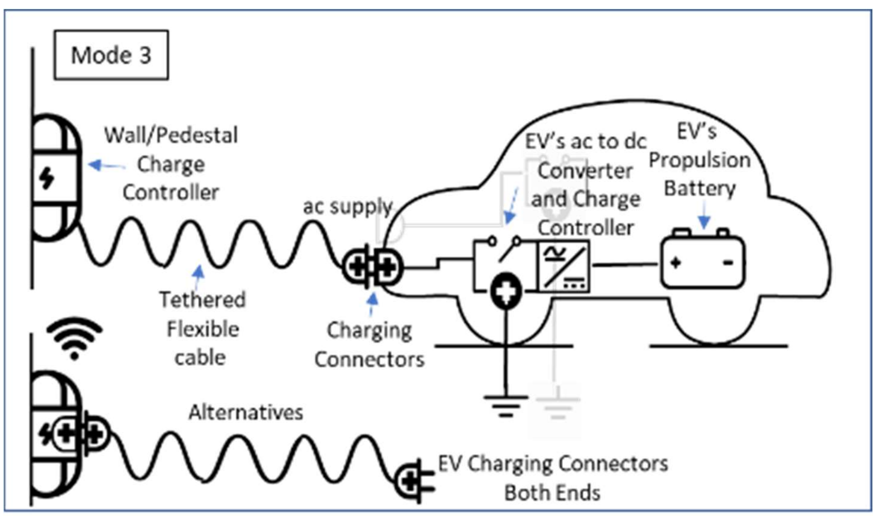

Figure 4: Schematic of Mode 3 Charging Including the Electricity Circuit from the Mains Supply.

For Mode 3, the EVSE is permanently connected to the electricity supply and provides a control pilot function and safety features similar to the IC-CPD that protect against electric shock.

A wall mounted charger with tethered cable

A public, roadside charger connected with a separate, portable charging cable

Figure 5: Examples of Mode 3 Charging

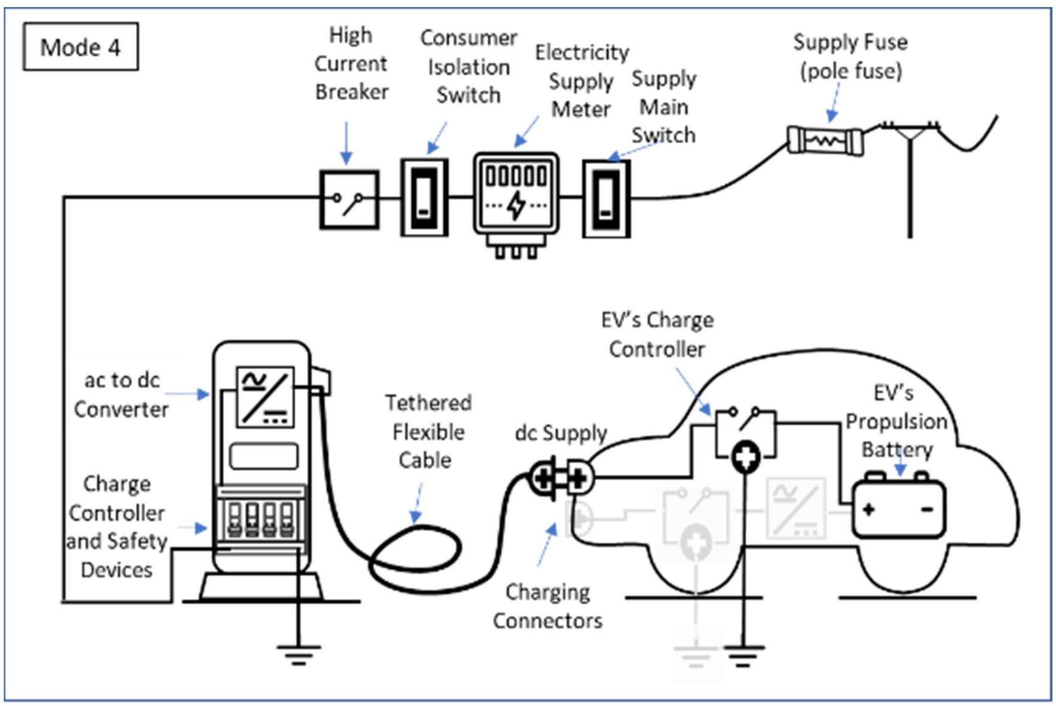

Figure 6: Schematic of Mode 4 Charging Including the Electricity Circuit from the Mains Supply.

In Mode 4, the ac to dc converter is off-board the EV and the EV is provided with a dc charging supply. Combined EV and charger systems provide pilot functions and safety features that protect against electric shock.

Figure 7: Example of a Fast Charger, in this Case Providing Customers with a choice of CHAdeMO and CCS dc Charging. This Charging Station also Provides Fast ac Charging via a Type 2 Charging Connector.

2.2. Charging Interoperability and Safety

Charging equipment is designed, manufactured and installed to meet various recognised regulations, standards and guidelines to provide interoperability (the ability for vehicles and chargers to match so that one model of charger can be used to charge a wide range of EV models – ensuring that charging equipment and EVs have matching connector plugs and sockets is only one part of this) and safety. And part of a government's EV programme is to ensure that those regulations, standards and those guidelines that are important are known and are complied with.

In this respect guidelines compliment the standards and regulations that might be put in place by providing guidance when there are choices that installers and/or users of charging equipment can make. Examples include:

- Providing guidance on the preferred charging connectors to provide at public charging stations – there are choices, and providing guidance will make it more likely that an EV operator will be able to charge their EV when using public chargers.
- Providing added safety – the standards concerning the design and operation of charging equipment means that, apart from Mode 1 charging, the charging circuit along the charging cable and through the various connectors does not become live until the plugs and sockets are well connected, there is pilot communication between the vehicle and the off-board charging equipment, and various safety devices that monitor the charging circuit do not detect any faults. Because of this safety checking, it is also safer for the charging equipment to be switched on before it is plugged into the vehicle. Guidelines can encourage this best practice so that it becomes normalised.
- Encouraging the use of safety devices for ac charging that isolate the charging equipment when current leakage to ground is detected (indicating a potential hazardous fault with the equipment. The use of such safety devices is a standard requirement for dc charging).

- Guiding installers to place wall-mounted charging equipment at least 800mm above ground level reducing the risk of impact damage from vehicles, reducing the risk of damage from flooding, and others.
- Guiding users of portable in-cord control and protection devices (IC-CPD)so that they do not use them in an unsafe manner including not adding any other appliance to the circuit when charging (i.e., do not use multi-plugs) and not using extension cords (which risks compromising the safety provided by the earth circuit).

3. Charging an Electric Vehicle

As has been mentioned, charging is easy. Let’s first go through the steps to charging an electric vehicle (EV) using an ‘In-Cord Control and Protection Device’ (IC-CPD) – the portable charging cable normally supplied with an EV when it is purchased.

3.1. Mode 2 Charging

The steps to using such a portable charging device (Mode 2 charging) are:

1. Stop the EV, engage the hand brake, and turn the EV off.	
	2. Release and open the door to the vehicle's charging port and open any additional cover that may be over the vehicle's charging connector, should one be fitted.
3. Ensure the IC-CPD is fully plugged into a suitable socket outlet. Turn the socket outlet switch on and make sure the IC-CPD status light is correctly luminated.	
	4. Orient the EV charging connector correctly and then push it firmly and fully into the vehicle's charging port connector.
5. Wait 10 seconds to check that charging has begun.	
	5. You may also want to use the EV's charging timer to delay the start of charging to when off-peak electricity rates apply. Some charging equipment also has this capability, including some where this delay can be easily set through a connected smartphone and application (app).

Figure 8: The Steps to Charging an EV using a Portable In-Cable Control and Protection Device Cable.

Ending the charging event depends upon the charging equipment involved. Some have a touch sensor in the head of the charging connector that will stop the charge when it detects someone trying to pull the connector out (but will not release the connector until the charging current has stopped and the individual connectors are no longer live). Others have a push-button in the handle of the charging connector to trigger the end of charging. Once charging has stopped, the charging connector can be removed from the vehicle. Stow the connector and charging cable to avoid damage to it and to avoid the cable becoming a trip hazard.

Note that Section ??? considers the supply of electricity to the socket outlets, and the type of socket outlet and plug recommended for use for charging in PICs.

3.2. Mode 3 Charging

Mode 3 is ac charging where the off-board charge controller and safety protection device is permanently wired to the electricity supply circuit (i.e., rather than plugged into a socket outlet as is the case for Mode 2 charging). The charging equipment is normally wall or pedestal mounted.

Mode 3 is recommended for ac charging in public areas because it is more robust and the permanent wiring is also inherently safer. Often ac charging equipment in public spaces also requires access via a radio frequency identification device (RFID) or app on a smartphone to avoid unauthorised use. This can also be used to identify the user for automatic billing purposes, if set up for this. Below are the steps used to charge from a public ac charging station where the EV operator provides their own portable charging cable to connect their EV with the charging station.

1. Stop and turn off the EV, release and open the door to the vehicle's charging port and open any additional cover on the vehicle's charging connector, should one be fitted.	
	2. Swipe the RFID tag across the sensor (or use your smartphone app). The charging station should acknowledge access (be it by sound or lights indicating the charging station has been activated.
3. Plug the charging station end of the portable charging cable into the charging station.	
	4. Plug the other end of the charging cable into the EV's charging port.
5. If charging does not automatically start, you may also need to push a start button on the charging station. This button may be flashing to make you aware of the need to do this.	
	6. If leaving the vehicle unattended, consider using the EV's connector lock to avoid an unauthorised person unplugging your EV. This also keeps the charging cable secure.

Figure 9: The Steps to Charging from a Typical ac Public Charging Station

Ending the charging event depends upon the charging equipment involved. Some chargers in public spaces require RFID or smartphone/app access to stop the charge event (to prevent an unauthorised person prematurely stopping the charge event). Some have an unlock latch on the handle of the charging connector that stops the charging event when triggered. Some require the 'STOP' button on the charging station to be first depressed. The exact method required is normally intuitive.

Interlocks on the connector normally prevent the charging cable connectors from being uncoupled until charging has stopped and the charging circuit is no longer live. Uncouple the charging cable beginning at the coupling with the vehicle, then coil, and stow the charging cable. The charging cable is normally supplied with a bag to make it easy to stow in the boot of your EV.

The charging cable may also be tethered to the charging station, avoiding the need for the EV operator to supply their own cable. If using this configuration, the cable should be put back on its hanger or otherwise stowed once charging has been completed to avoid the risk of damage to it or to avoid it becoming a trip hazard.

A schematic of these two Mode 3 options – using tethered and non-tethered cables – was provided in Figure 4.

Through the use of guidelines, most Mode 3 (ac) public charging stations outside of China now terminate in female 'Type 2' socket outlets and rely on the EV operator to provide their own charging cable. This enables an EV operator to purchase a charging cable with a matching Type 2 connector at one end and whatever connector matches their EV at the other. Some at-home charging stations are similarly specified to provide different vehicle connectors using one charging point outlet (and provide future-proofing of the charging equipment should an EV purchased later have a different ac charging connector).

Another advantage for the use of a separate charging cable for low- and medium-speed public ac charging is that the EV operator takes the charging cable away at the end of the charge event, removing a potential trip hazard.

3.3. Mode 4 Charging

Mode 4 (dc) charging stations are normally public charging stations and the operating procedures are much the same as for Mode 3 public charging only that the charging cable is always tethered – the cable is large to carry the large currents involved with fast charging and is required to be tethered. Figure 10 provides the procedure for fast charging.

1. Stop and turn off the EV, release and open the door to the vehicle's charging port and open any additional cover on the vehicle's charging connector, should one be fitted.

2. Swipe the RFID tag across the sensor (or use your smartphone app). The charging station should acknowledge access (be it by sound or lights indicating the charging station has been activated).

3. Withdraw the correct charging connector from the charger.

4. Plug the connector into the EV's charging port.

5. Push the start button on the charging station. This button may be flashing to make you aware of the need to do this.

6. Many dc public chargers lock the connector in place and requires the owner to activate an end to charging (by RFID or phone/app) before it is unlocked. Therefore using the vehicle's connector lock may not be necessary.

Figure 10: The Steps to Charging from a Typical dc Fast Charger

As for public ac charging, ending the charging event depends upon the charging equipment involved. Many chargers in public spaces require RFID or smartphone/app access to stop the charge event (to prevent an unauthorised person prematurely stopping the charge event). In the case of using RFID, registration by swiping the tag across the RFID sensor will likely cause the stop button to be illuminated, and pushing this button will stop the charging process, unlock the connector, and allow the connector and cable to be withdrawn.

For all charging modes, the battery management system (BMS) that is a part of the battery system guards against over temperature of the battery cells (the charging process creates heat), overly high charge rates, and overcharging. For the last, the BMS will stop the charging event once the batteries are fully charged. But care should be taken when charging at public charging stations as some may charge for both power transferred and time connected – and an EV that has completed its charge but is still connected may still be incurring fees.

4. Supply of Electricity to the Charging Equipment

4.1. The Customers Electricity Supply Circuit

The current draw associated with slow-to-medium rate ac charging equipment typically ranges from similar to that for an electric kettle to similar to that for a large domestic air conditioning unit. There are also some 'fast ac chargers' – the charging connector on the very right of the multi-connector charging station in Figure 7 shows an example of this[1].

As for any electrical appliance, the electricity circuit supplying electricity to charging equipment must be capable of safely providing the necessary current – and the safety breakers, socket outlets, plugs and supply cables between must be suitably rated for the charging equipment they supply. Figure 11 provides a schematic of the components making up the power supply circuit in the case of the use of a portable charging cable (i.e., as in Mode 2 charging), beginning from the supply of electricity to the consumer. The various components in this electricity circuit comprise:

- A supply fuse (sometimes called a pole fuse as this tends to be its location in overhead distribution systems).
- A supply main switch, allowing isolation from the mains supply.
- A meter used by the electricity supplier for revenue purposes.
- A consumer main switch.
- A distribution board through which the electricity is supplied to the downstream supply circuits, each supplied through their own safety circuit breaker. These circuit breakers are designed to fuse and isolate the downstream circuit when there is excessive current.
- In preference, a circuit providing EV charging would also have residual current device (RCD) protection. RCDs, also known as a residual current circuit breaker (RCCB), a ground fault interrupter (GFI), or a ground fault circuit interrupter (GFCI), will also break and isolate the downstream circuit if it detects a hazardous leakage of current to earth (which indicates another type of fault).
- A wall socket outlet, allowing the portable In-Cord Control and Protection Device (IC-CPD) to be plugged in and connected to the mains supply.
- The IC-CPD which communicates with the EV's charge controller through a pair of communication wires in the flexible cable. Together they enable the charge event to be controlled. The IC-CPD also passes the controlled ac current supply to the vehicle (reason for why this is referred to as 'ac charging') and terminates in a standardised charging connector.
- Matching, standardised charge connectors enabling the IC-CPD to plug into the EV's charging port connector, and allowing the charge current to pass and communications between the EV and the IC-CPD.
- An on-board converter that converts the incoming ac supply to the dc supply required to charge the propulsion battery – batteries are dc devices. The EV also has a controller that

[1] However, there are relatively few EV models that are capable of fast ac charging capability – reason why many fast chargers now provide only dc CHAdeMo and dc CCS Type 2 charging connectors at fast charging stations.

controls the charge event and parts of this controller are normally integrated with the ac to dc converter.

- The EV's propulsion battery.

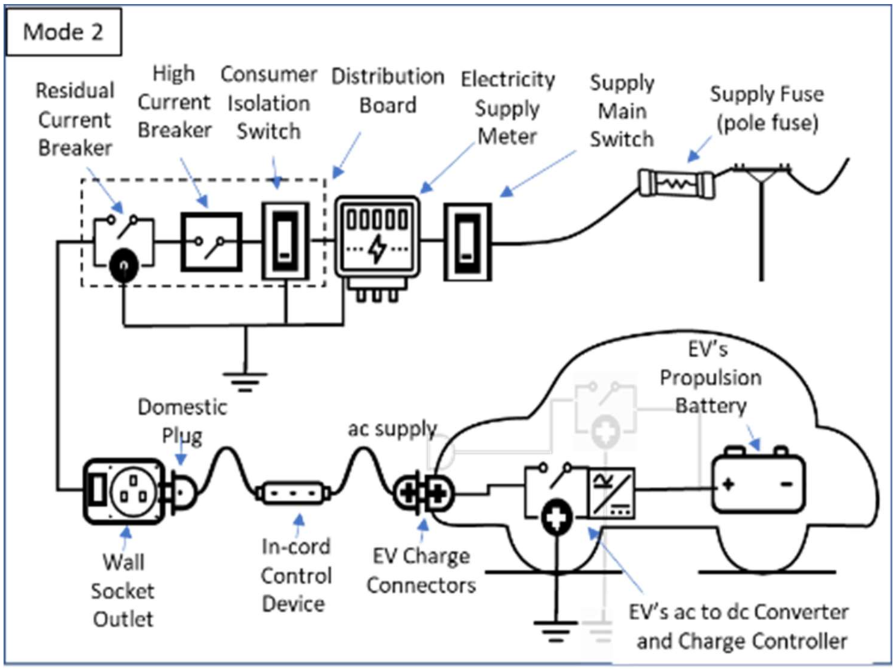

Figure 11: The Main Electrical Components when Charging an EV from a Socket Outlet

Mode 3 charging has a similar electricity supply circuit to this Mode 2 circuit example, only that the socket outlet of the Mode 2 charging circuit is removed as the off-board charging equipment is directly wired back to the breakers at the distribution board.

The full electrical circuit, from the power station to the EV's propulsion battery, must be safe. Regulations, standards and guidelines help define what is considered safe. Providing examples of how they do this:

- Governments mandate that only approved electrical appliances can be sold and used. To be approved, a manufacturer must carry out certain conformity tests and label the appliance accordingly. One of the requirements is that the (labelled) range of electricity supply voltages and frequencies covers that of the country's power supply. In this regard, there is a risk that the IC-CPD portable charging cable is not rated for use on the local grid where it has come from a used EV import imported from a country that has a different mains voltage and/or frequency – and it is good practice to identify and dispose of these charging cables at the time of import inspection so that they do not enter the market to begin with. This would need to be reinforced with checks in the marketplace.
- A country's wiring regulations standardise the size of breaker, size of cable and style of socket outlet to avoid over-stressing the electricity supply circuit. Higher-power appliances that still use socket outlets and plugs, such as powerful air conditioning units, are specified so that their plugs cannot fit into socket outlets on low-power electricity supply circuits (and only qualified electricians are permitted to change the plug on an appliance, to avoid a mismatch of current draw from an appliance and what the power supply circuit is designed to safely provide).
- Governments also mandate that charging equipment must meet certain internationally recognised standards. These standards provide a suite of safety features that protect the

equipment and the user. An example already mentioned is the way in which interlocks work so that the connectors that carry the charging current when charging and electric vehicle are not live before, during coupling or decoupling, or after decoupling.

- Standards governing the design of charging equipment also result in charging equipment operating at a charging rate that matches the least-rated component of the charging equipment circuit, be it the rating of the charging cable, the IC-CPD, the vehicle's on-board ac to dc converter, the EV's charge controller, or what the EV's battery's battery management system calls for.[2] Hence no one component should be in a situation that it becomes stressed.
- Guidelines in many countries provide added safety measures. In recognition that ac charging from a socket outlet can happen at near to the peak design current for a given supply circuit over many hours, and not just minutes as for many household appliances, many countries have stipulated the use of lower rated charging equipment unless a temperature cut-out is included in the plug of the portable charging equipment.

Together, these regulations and standards provide a system that is inherently safe in all weathers (the series of photos provided on the earlier pages to show how to charge were purposely taken while it was raining), and even should a fault occur. In addition to these, guidance is provided to help operators use charging equipment and premise power supply circuits wisely. This is particularly relevant for people using portable charging equipment (Mode 2 charging) as there is a risk that the power supply circuits can be overloaded because users are not aware of the issue. For example, through the use of multi-plug boards, or premise circuits where the same wiring supplies more than one wall socket outlet, it would be possible to charge an EV at the same time as power is drawn by another electrical appliance – and the resulting current may be higher than the circuit was designed for.

4.2. The Effect of Electric Vehicle Charging on the Electricity Network

Unless a local electricity supply network was already stressed by existing demand, it would be unusual for the from charging an EV to cause a noticeable reduction in the quality or security of supply to others on that network. Further, many electricity supply services in urban areas have reasonable spare capacity and in such cases it could be expected that several EVs could charge at slow charge rates without affecting the electricity supply.

However, there is the potential that an EV might not be able to conveniently charge from a network that is already operating over its peak capacity. For example, the quality of electricity can be poor in remote areas when supplied by a low-capacity electrical supply line that is stressed by overuse. In such a case, voltage droop or other compromised power quality could trip and stop a charger working until the charger is reset. Watching over and resetting a charger many times over a 10-hour charging event would be tedious. Setting your EV to charge overnight and finding the next morning that it has not been charged could be even more frustrating. The added load of EV charging on such a stressed supply circuit might also cause further power quality issues. The lesson here is that EV charging in remote locations may require additional management to ensure that it is reliable as well as safe.

[2] The BMS can change the charging rate during a charging event. For example, an EV with a 50kW d.c. charging system charged by a 50kW d.c. fast charger may only see a charging rate of 50kW when the battery is between around 20% and around 50% state of charge (SOC), with the charge rate steadily decreasing after that to avoid those SOC levels where higher degradation of the battery might occur, right through to the point where the BMS will stop the charging event altogether when it identifies that the battery is fully charged. These variations in charging rate are often quite specific to models of vehicles. Another model of EV might have a much flatter charging rate profile because of differences in total battery capacity and chemistry,

In the future, the capacity of an existing electricity distribution network might also become insufficient as the number of EVs charging from it increases. For example, this might happen at a local distribution network level if a neighbourhood ends up with a cluster of EVs that are 'at-home' charged. Upgrade of the local distribution network may be required, which tends to be very expensive. The need to upgrade might be avoided, or at least deferred, if the time at which these EVs are charged is managed so that charging does not coincide with peaks in demand from other loads on the network – reason for why it is often encouraged to home-charge electric vehicles through the night after the peak evening load subsides.

There are various options for such electricity demand management. The EV owner may simply manually switch charging on and off to suit (which is simple and works but might not be particularly reliable). Or else automated systems, including those that allow the electricity supplier to manage the time and charging rate of a charging event, may be used. With 'smart metering', the electricity supplier can also use time-of-use electricity pricing to incentivise electricity use during off-peak periods. There are also 'smart' chargers available that can manage the charge according to other demands on a single electricity connection or manage charging across a neighbourhood of (cloud-connected) chargers for only slightly more than the cost of unmanaged 'dumb' chargers.

Taking managing EV charging a further step, technology is emerging that allows the use of the batteries of EVs to supply electricity to the local electricity network, rather than take it. This vehicle-to-grid (V2G) arrangement can benefit the local grid in several ways. However, commercially, such is still many years away and currently there are also cheaper and easier ways to provide the same service. It is therefore not discussed further in this background on charging other than to say it will be worth revisiting V2G when it becomes more developed and commercial.

Another factor is the increasing (at-home/at-work) a.c. charge rates that new EV models are capable of. Faster charging rates are more convenient … it takes less time to charge an EV, providing more flexibility of when an EV is charged. These higher charge rates can be more than standard domestic socket-outlets can handle and higher rated sockets and plugs are required for such charging, or preferably the charging equipment is hard-wired right back to the switchboard. Also, as higher rate a.c. charging might have a similar demand to charging three to five EVs at low charge a.c. charger rates, the use of these higher charge rates would not be a good match with low-capacity electricity supply networks. Note that a higher a.c. charge rate EV model can also be charged at a lower rate, and it is normal that higher rate chargers can also be controlled to charge at lower rates.

Most recent model EVs also have d.c. (direct current) charging capability which provides a much higher rate of charge than charging an EV from an a.c. (alternating current) electricity supply. This is because charging from a mains a.c. supply first requires the conversion of a.c. into d.c., and a.c. to d.c. converters can be heavy and expensive – limiting the size of converter that a manufacturer will use on a vehicle. Take that converter off the vehicle, then a much larger converter can be used and much higher charge rates can be achieved. Until recently, 50kW was a common rating for such an offboard 'fast' d.c. charger (which compares to the maximum charging rate of a portable changing cable arrangement of less than 2kW (2kW is about the same power as that of a fast domestic kettle used to boil water)). EV models and d.c. chargers capable of 150kW charging rates ('ultra-fast charging') and even higher are now entering the market. And chargers built for specific commercial projects (such as for charging e-buses) may provide charging of anything between 450kW and 1MW (which is sufficient to provide power to 400-500 'electrical appliance busy' households).

As mentioned, fast chargers (50kW) are very heavy and expensive (and larger capacity chargers are more costly again) and are therefore impractical for at-home charging. However, they do have an essential role in providing public fast charging. Because fast chargers are expensive, it can be difficult to make the provision of fast charging economic, particularly at the start of a nation's EV campaign when there is only a low population of EVs from which costs can be recovered. For this reason, the initial development of a fast-charging network often depends upon government or aid funding, or some very creative justification if taken on unsubsidised by a private party.

In a PIC situation, electricity supply networks are often already working at, near or even over their peak capacity and there is a high risk that the local distribution network would require upgrade to cater to the needs of a fast charger. Such an upgrade can be expensive. Because of the sensitivity to cost, finding a site that does not require a network upgrade is sometimes a deciding factor in where fast chargers get installed.

Different charging arrangements are required for different situations. A high proportion of charging is expected to take place at home (if the experience of countries where EV use has become well established is anything to go by, around 90% of charging is carried out at home), making the most of the long periods of time when a vehicle is parked. At-work charging at slow rates might also be provided where EVs are parked for a time. Higher charging rates would likely be required in a work environment where EVs are used often, to avoid downtime. Hotels might install slow charge rate charging points to attract customers. Shopping centres might provide charging facilities to attract customers or might make access to land available as an incentive to a charging station provider to set up a conveniently located charging station. Towns and cities might set up roadside charging facilities as they play their part in encouraging the uptake of EVs. And the commercial sector, including bus operators, may set up dedicated fast and ultra-fast charging facilities. These arrangements place different demands upon the electricity supply and tend to draw electricity at different times of the day. Those that operate the chargers will also have a range of skill levels. All of these factors need to be taken into account when considering the effect of charging on the electricity supply system and how charging infrastructure might be installed and used.

In summary:

- It would be expected that existing urban distribution systems could provide for unmanaged, low charging rate charging for the first EVs in the neighbourhood, but a higher uptake of EVs may require some degree of managed charging and/or upgrade of the electricity supply network supplying them – a good reason to encourage the uptake of charging points that are capable of being remotely managed from the outset in a country's EV programme.
- There is a risk that the installation of fast chargers will require an upgrade of the local electricity supply system.
- There are a range of charging arrangements and methods by which an upgrade to the supply network may be unnecessary, or at least it could be deferred.

5. Background on Electricity Supply Systems

5.1. Detail

5.1.1. Makeup of the Electricity Supply

Most domestic connections to the electricity supply network are two-wire 'single phase' connections, comprising a 'live wire' and the 'neutral wire' (which, despite its name, is very much live). For PICs, the voltage across the two wires is 240 V a.c. (alternating current) and cycling at 50 Hz (cycles per second). Samoa's single phase electricity system is at 230V and 50 Hz.

Connections to commercial and industrial sites along with some domestic sites that have a high load requirement might be 'three phase' electrical supply. Three phase is supplied as a four-wire system comprising three phase wires with 415V a.c. at 50 Hz across any two phase wires (and hence the supply is often referred to as a 415V supply) and a (live) neutral. These single and multi-phase supplies are provided from the same electricity distribution network: the single-phase supply is delivered simply by selecting one of the three phase wires plus the neutral wire (which, because of the timing of the cycling of voltage between them, arrives at 240V a.c. across the two single phase wires).

5.1.2. Earth Connection:

With the exception of supply to low-power socket outlets in some countries and some low-power lighting circuits, the electricity cables that are run around a site tend to be three-strand – comprising a phase, a neutral and an 'earth' wire. The earth wire and its circuit provide important safety functions. A TT[3] protective earthing system is normally used in many PICs. This is where the earth circuit begins at a large rod conductor staked in the ground somewhere on site. An earth wire connects this conductor to the distribution board from which the earth wires to socket outlets and appliances are run. In the case of many appliances, this earth circuit is connected to the outer conducting parts of the appliance. If an electrical fault occurs, the earth circuit provides a safe path for most (if not all) of the fault current, and this also normally trips the supply circuit's fuse or other protective device, shutting off the supply of electricity to the appliance and making it safe.

There are also so-called terra-network (TN) arrangements, where the earth is provided by the electricity network though an additional earth wire in the supply to a customer. There are also combinations of TT and TN arrangements. Whichever configuration is used, the important thing to note is that the earth circuit provides an essential safety function, and it must be present, robust and compliant with the requirements set out by the local controlling authorities. A check of 'earth continuity' is a built-in safety feature on most EV charging arrangements, which means they will not operate without a functioning earth connection.

5.1.3. RCDs

The most commonly used RCD (Type A) is principally designed for providing protection on a.c. circuits, and is therefore quite suitable for normal a.c. supplies connected to standard appliances. However, charging an EV involves d.c. currents (at some stage the a.c. mains electricity is converted into d.c. in order to charge the propulsion batteries) and there is a small risk of a fault condition in which a hazardous d.c. leakage current develops. A Type A RCD will trip on detecting hazardous residual pulsating a.c. current but might not trip if there is a hazardous smooth residual d.c. current. Some jurisdictions call for added measures to manage this risk. The most common methods are:

- The use of a Type B RCD, which has both a.c. and smooth residual d.c. monitoring and tripping functions.
- The use of a residual direct current detection device (RDC-DD) which provides smooth residual d.c. monitoring and tripping alongside the use of a Type A RCD, which provides the a.c. monitoring and tripping function.

Type B RCDs are quite expensive compared to Type A RCDs. Some charging points have inbuilt RDC-DDs and arguably therefore only require Type A RCD protection on the electricity supply circuit to provide protection against both a.c. and d.c. residual currents.

5.1.4. Quality of Work:

Wiring rules and regulations have requirements with respect to the quality of workmanship and components used, and that designs and installations are fit for purpose. (If equipment is installed outdoors, for example, components must be specified that provide the necessary protection against the weather. Similarly, the use of various forms of protection mechanisms to avoid damage to installations must be fitted).

[3] TT or terra-terra. Terra is Latin for earth or land, and the first T means that earthing is provided to the power supply equipment (generator of transformer) and the second T means that a local in-the-ground earth (such as an earth rod conductor) is provided on the (customer's) site of where the electricity is used.

5.1.5. Plugs and Socket Outlets for Mode 2 Charging

The IEC Type I socket outlet and plug (AS/NZS 3112, Figure 12) is commonly used in the Cook Islands, Fiji, Samoa and Tonga (and is also the standard socket outlet and plug used in New Zealand and Australia). This has a three, flat pin arrangement and the standard socket outlet is rated for 10A. Although 10A is the nominal continuous use rating, there are few appliances that would require many hours of use at 10A. For example, a hot water kettle might be on for 3-5 minutes. A stove top might be on for 10-15 minutes. An air conditioning unit or an electric oven might be on for several hours, but it is normal that these are either direct-wired to the distribution board or they use higher-rated sockets and plugs.

The introduction of EV charging changed this – it became possible to charge an EV using a 10A charger for 10 or more hours (the time it takes to fully charge a Generation 1 or 2 Nissan Leaf starting from a low State of Charge (SOC) starting point). The 10A socket outlet and plug, and possibly the size of the cable supplying electricity to the socket outlet, were not necessarily designed for this. There have been cases where connections at socket outlets became so hot that the plastic around them scorched. These risks were managed in a number of ways. One was permitting the use of 8A portable charging cables only unless the plug has temperature sensing, in which case a 10A charging cable could be used. Another was using a higher-rated plug (in some cases using a 20 A three flat pin plug that could be forced into a standard outlet, which was not a good management option. Other higher rated socket and plugs are preferred for this reason). Note that it is illegal to change the type of plug used on an electrical appliance unless the work is carried out by a suitably skilled person (to avoid a mismatch of plug and socket that may result in overloading the electricity supply circuit components).

Figure 12: Example of a Type I Socket Outlet and Type I Plug (AS/NZS 3112)

6. The makeup of Charging Guidelines

Governments around the world have the responsibility to provide a safe environment. With respect to the use of electricity, there is a general requirement that electrical installations must be safe. Regulations, standards and guidelines are then used to describe what is considered safe through providing minimum requirements for the design, construction and verification of electrical installations, providing descriptions of acceptable installation practices, and providing recommendations. Compliance with regulations is mandatory. Governments also make certain standards concerning electrical installations mandatory. Governments around the world have also adopted a number of internationally recognised standards concerning electric vehicle charging. These not only ensure safety for people, equipment and the electricity supply system, but they also make charging easy and make charging systems and electric vehicles interoperable (i.e., they can talk to one another and work together).

Sometimes additional information is required to guide practitioners or the wider industry. For example, regulations and standards may allow the use of a number of standardised charging connectors. Guidelines can then be used to encourage the use of particular connectors, making it more likely that the connectors on public chargers match those required by the majority of the EV fleet. Guidelines are also useful to manage the introduction of new technology, such as EVs, as they can be used to relatively quickly manage issues as they arise (whereas standards can take several years to develop and introduce) and are normally sufficiently flexible that they do not set barriers to new ways when they present themselves (so long as those new ways are safe).

To an informed practitioner in the field, the guidelines are simple, merely putting into words what is common sense. However, EV technology is new and one function of the guidelines is to better inform those who have yet to become familiar with the technology.

There is also a need to get some of this information right through to those people who may not have a technology background but who own an EV and need to know how to safely charge their vehicle – for example, the information relating to the use of portable charging equipment where the 'installation' comprises plugging in and turning on … and is outside the control of skilled installers. Information on RCDs and earth connections will likely be lost on most EV users. However, the guidelines should provide a base from which to draw critical messages. These could be take the form of a one- or two-page 'infographic'. And it is proposed that this guideline development work extend to the development of the main messages to provide in such infographics (which individual countries may wish to craft into charging point stickers, posters and brochures themselves, to incorporate traditional art and languages).

7. Proposed Industry Guidelines:

7.1. Introduction:

Electric vehicle supply equipment (EVSE) is any equipment that performs recharging of electric vehicles and includes cables, connectors, chargers and control and safety systems. These guidelines provide information and guidance for the installation and use of EVSE. They are aimed at a wide range of people, from everyday users of electric vehicles to those in the industry responsible for designing and installing charging equipment and installations. They aim to help with compliance with mandatory electricity safety regulations, referenced standards, and codes that are in place (but these guidelines are not to be used to provide alternative pathways to obligatory requirements), and aim to make charging simple and safe.

7.2. Scope:

These guidelines apply to the conductive charging[4] of 'mainstream' four-wheeled electric vehicles (EVs), including electric buses and other heavy commercial vehicles – the sort of passenger and freight vehicles that are used on public roads. These guidelines include details relating to the specification of EVSE and its installation, and how EVSE should be used.

These guidelines are not intended to cover:

- Very low charge rate charging such as that typical of two-wheeled or smaller format 'micromobility' electric vehicles.
- Ultrafast charging (which tends to require site-specific and specialist input into its design and installation).
- Non-standard charging of EVs, including that carried out during testing and repair of EVs or during research and development.

[4] Conductive charging is where connectors and wires are used to connect the EV with the charging equipment. Another type of charging is inductive charging which is achieved without contact. Inductive charging is not commonly used and is not further considered in these guidelines.

7.3. General Philosophy

Any EVSE installation, including portable EVSE, must be safe, and the EVSE must be safe to use. The fundamentals of ensuring such safety include:

1. **Rules and regulations** – Install and maintain EVSE in accordance with the national rules and regulations concerning electrical installations, and any standards they refer to.
2. **Intended purpose** – Only using EVSE for its intended purpose – to charge an electric vehicle.
3. **Rated value –** Always using any component of EVSE within its displayed, rated value (for any components within the electricity supply chain, from the connection to the premises/site right through to the connection of EVSE to the EV and including the wires in the cables).
4. **Earth circuit –** Avoid EVSE arrangements that might have poor earth circuits (including not using extension cords or adaptors other than those specifically approved for the application. In this respect, permanently wired EVSE is inherently safer than portable EVSE that use mains electricity socket outlet connections).
5. **Damage** – Do not use EVSE that is damaged.

Each has its place in making electric vehicle charging safe. For example, rules and regulations that the manufacturer of electric vehicles follows assure that the electric vehicle is inherently safe to use and to charge. National wiring rules provide requirements for the specification of electricity supply circuits, including the specification of socket outlets and plugs, cables and safety breakers, to prevent a situation where an appliance calls for currents that are higher than that that can be safely delivered by the supply circuit. And national wiring rules provide similar guidance for the earth circuit, aiming to ensure that this important safety element of electricity supply is robust.

The following general guidelines are based on applying the above five safety fundamentals to vehicle charging:

7.4. General Requirements:

1. National rules and regulations concerning electricity installations, including for the installation and use of charging equipment, must be complied with.
2. The installation of EVSE and the use of EVSE must be safe.
3. Only EVSE shall be used to charge an electric vehicle.
4. All EVSE must be fit for purpose:
    a. The EVSE must be labelled by the manufacturer with its electricity supply requirements and must not be used with electricity supplies that do not match.
    b. The EVSE must be labelled by the manufacturer with its rating and must not be used at a higher rating. Protection devices must also be used to prevent excessive loading of the electricity supply and EVSE.
    c. EVSE shall be either compliant with relevant IEC standards or relevant UL standards, and be labelled as such, and a supplier shall provide proof of compliance if requested by a Government Authority charged with performing such checks. In this respect:
        i. Mode 2 EVSE should be compliant with IEC 61851-1, IEC 62752 or UL 2251, as applicable.
        ii. Mode 3 EVSE should be compliant with IEC 61851-1 or UL 2251, as applicable.
        iii. Mode 4 EVSE should be compliant with IEC 61851-1 and IEC 61851-23 or UL 2202, as applicable.
    d. EVSE must have appropriate weather and dampness protection for its application.
    e. EVSE must be designed, built and selected to withstand normal use. This includes ensuring that EVSE has appropriate weather and dampness protection for the

specific application. The use of bollards or other means may also be required to avoid impact from vehicles.

5. Any installation, use, testing, verification, maintenance and repair of EVSE, or parts thereof, shall only be carried out by people who are competent to carry out such tasks.
6. EVSE shall only be used if all connectors and plugs between the electricity supply and the vehicle match.
    a. No socket-outlet adaptors are permitted to be used.
    b. No charging-type adaptors are permitted to be used unless approved by the manufacturer of the electric vehicle.
    c. No connectors or plugs are to be changed unless this work is carried out by a competent technician who is authorised to carry out such work.
7. Each supply circuit from the switchboard shall charge no more than one EV at a time.
    a. No multi-plug outlet arrangements shall be used.
    b. As an exception, an arrangement that has been specifically designed for the purpose of charging multiple EVs from the same power supply can be used if the arrangement robustly and automatically limits the total current draw so that the rating of the electricity supply circuit is never exceeded.
8. Do not use charging equipment that is damaged.
    a. Damage may show itself either as physical damage or as an electric shock to a user.
    b. If a public charger, report the damage to the contact named on the charger's notices (on the side of the charger), or the supplier if a private charger. Do not use the charger until it has been tested and verified to be safe.
    c. Some degree of superficial damage can be accepted – you do not throw away a vehicle because it is dented, or a charging cable if it is scratched. But if any connectors are cracked, cables have cuts in them, there are loose components, or potentially live components are visible, then do not use the charging equipment.

7.5. Requirements Specific to Different Charging Modes:

Mode 1 Charging (where an EV is charged from a socket outlet using a cable that does not have an in-cable charge controller).

9. Mode 1 charging is only permitted for home-based charging of a private vehicle. The use of Mode 1 charging is not encouraged because it is inherently less safe than other charging mode.
10. Where it is necessary, Mode 1 charging must be provided through an RCD with at least Type A performance (tripping at not greater than 30mA residual a.c. or 6mA residual pulsing d.c. and isolating all live conductors, including the neutral). Preference is to supply Mode 1 EVSE through protection that also trips at 6mA smooth residual d.c. (i.e., including through the use of a residual direct current detection device (RDC-DD) alongside the use of a Type A RCD, or through the use of a Type B RCD on the electricity supply circuit).
11. Additionally, an EV must be electrically grounded throughout a Mode 1 charging event – the conductive body parts of a Mode 1 charged EV must be connected to the earth pin of the connecting plug, the earth pin must be extended to make contact before the live and neutral wires when plugging in, and the earth circuit of the socket outlet must be present and robust. A two-pin plug or a two-pin socket outlet cannot provide this and must not be used.
12. An extension cord must not be used.
13. The maximum current for Mode 1 charging is 8A (1.9kW at single phase 240V a.c.).

Mode 2 Charging (where an EV is connected to a supply of electricity through a charging cable with an In-Cord Control and Protection Device (IC-CPD)):

14. Mode 2 is not permitted for public charging or for charging an EV in a public area.

15. A Mode 2 charger must not be plugged into a socket outlet of a site that is only supplied a low-power connection unless that socket outlet and its supply circuit has been inspected by a competent electrical inspector, verified as rated for the application, and the socket outlet is clearly marked as suitable for EV charging. [check relevancy in the case of PICs]
16. A Mode 2 charger must have earth continuity monitoring (where a break in the earth connection of an EV to the earth of the electricity supply circuit's earth protection circuit stops the operation of the charger). This requires the Mode 2 charger to have a three-pin plug, the supply socket outlet to be three-pin, and the earth circuit to be complete between vehicle and electricity supply.
17. An extension cord must not be used.
18. Mode 2 charging device must receive supply through an RCD with at least Type A performance. Preference is to supply Mode 2 EVSE through protection that also trips with smooth residual d.c. (e.g., through the use of a Residual Direct Current Detecting Device (RDC-DD) alongside the use of a Type A RCD, or through the use of a Type B RCD as described for Mode 1 charging above).
19. The plug at the electricity supply to the IC-CPD must be rated for the application. For domestic applications:
    a. An AS/NZS 3112 (three flat pin, 10A rated) plug can be used for an IC-CPD rated up to 8A unless fitted with temperature sensing in the plug in which case it can be used with an IC-CPD rated up to 10A.

Figure 1: AS/NZS 3112 10A rated Socket Outlet and Non-Temperature Sensing Plug

    b. An IEC 60309-2 (three round pin, 16A rated 'caravan') plug can be used for an IC-CPD rated up to 12A unless fitted with temperature sensing in the plug in which case it can be used with an IC-CPD rated up to 16A.

Figure 2: IEC 60309-2 Mennes 16A rated Socket Outlet and Plug

Mode 3 Charging (where the EVSE is permanently wired to the electricity supply circuit, pilot functions within the EVSE control the charging event, and the EV is connected to the EVSE by a tethered or non-tethered charging cable with standardised EV charging connectors).

20. Mode 3 EVSE must not be able to operate unless it has earth continuity.
21. Mode 3 charging must be provided through an RCD with at least Type A performance in private charging situations. Preference is to supply Mode 2 EVSE through protection that also trips with smooth residual d.c. (e.g., through the use of RDC-DD alongside the use of a Type A RCD, or through the use of a Type B RCD as described under Mode 1 charging above). Mode 3 charging in a public space must be provided through an arrangement that either provides Type A plus RDC-DD performance equivalence, or Type B RCD performance equivalence.

22. Preference is for Mode 3 EVSE to possess functions that will allow remote management of the charge event.
23. The height that an EV charging connector is held when stored in a tethered charging cable arrangement should be at least 800mm above the ground level. The height of the charging-side socket outlet in a non-tethered arrangement should be at least 800mm above the ground.

Mode 4 Charging (where the EVSE provides a d.c. supply through a tethered cable with pilot functions controlling the charge event).

24. A Mode 4 charger must have short circuit protection, overvoltage protection, undervoltage protection, isolation monitoring, and earth continuity monitoring.
25. The height that an EV charging connector is held when stored should be at least 800mm above the ground level.

7.6. Recommendations for Public Charging and Charging Carried out in a Public Space:

In addition to those points provided above:

26. EVSE that is made available for public charging must be checked at least annually by an inspector or other suitably qualified person who is competent to provide this service.
    a. The date that the EVSE was last checked must be clearly indicated on the EVSE.
    b. The inspector shall provide the owner of the charger with a copy of their report and shall also keep a copy of the report for at least seven years.
    c. The report shall be made available to a government authority upon request.
27. Public charging stations must be provided with a lockable isolating switch that isolates the EVSE from all live conductors including the neutral.
28. In order to provide interoperability, it is recommended that:
    a. Mode 3 (a.c.) charging stations provide a Type 2 female socket (also known as a Mennekes a.c. socket outlet), with the EV operator providing their own flexible supply charging cable that has a Type 2 charging connector at one end and a connector that matches their EV at the other.
    b. Mode 4 (d.c.) charging stations provide tethered cables with both the CHAdeMo DC and DC CCS Type 2 connector types.
29. A public charging station must have clear safety and operating instructions for the charging equipment.

8. Proposed Key Messages for Public Infographic

30. The following key messages are proposed for the charging guidelines to be presented to the EV users through various forms of infographics. Note that these focus on users of IC-CPD portable charging cables as skilled practitioners should be installing permanently wired charging equipment and are obliged to understand the more detailed charging guidelines. The 'public' key infographic messages are:
    a. Know your charging cable – is it safe? Is it labelled? And does that label show it is compatible with the electricity supply?
    b. Know your electricity supply:
        i. Does it have the capacity to charge an EV?
        ii. Does it have safety protection to avoid a shock if there is a fault?
        iii. And remember, only one EV per socket outlet, and only one EV socket outlet per fuse or circuit breaker.
    c. Know when not to – do not use any charging equipment that is damaged.

9. Other Supporting Measures

31. There are various methods to deploy the proposed charging guidelines. They may be voluntary (but well publicised so that they are known and also easy to access). They may be voluntary with certain groups within the industry mandating that their practitioners abide by them. They may also be made mandatory by regulating authorities. It is also normal to first introduce such guidelines on a voluntary basis so that they can be tested before making the guidelines, or parts of them, mandatory.
32. There are also supporting measures that can be introduced. For example:
    a. An electricity supplier may provide a free assessment of the electricity supply to socket outlets that are intended to be used by a household for charging an EV. The reason to consider providing this service without a fee, at least initially, is that such an assessment will reduce the risks to the electricity provider's supply network as well. It may also avoid an incident that gives EVs a bad reputation – which would not be in the interests of an electricity supplier.
    b. Further on the last, a standardised label could be introduced to identify those socket outlets that have been inspected and meet the requirements, especially in regions where there is risk that the electricity supply circuits to socket outlets or the socket outlets themselves might not have sufficient capacity.
    c. In addition, it is proposed that those seeking further information on charging can be easily directed to short clips that demonstrate at-home charging and charging at public charging stations, preferably using a local charging station for the last.
    d. An EV owner may not know what to look for when checking to see if a portable charging cable is compatible with the mains electricity supply. If there is a high risk that there are non-compatible portable charging cables in the market, then perhaps a one-off test and tag or label system could be introduced so that the use (and sale of) non- compatible portable charging cables can be avoided. It may be necessary to provide a free test and tag/label service to encourage the uptake of this measure.