Power Plugs and Outlets in use in Europe – Charging from Single and Three-Phase Sources

Background

There are various different voltages and plug styles in use across Europe that are gradually being harmonised. While all systems work at 50Hz, voltages had traditionally varied from 220V up to 250V in different countries. From 2008, voltages in Europe have been standardised on 230V +/- 10%. In practice, this means that it is business as usual – there is still 240V coming out of UK sockets, for example, as it falls within the tolerance range. Therefore, the onus is on the appliance manufacturers to be able to accept the voltage variation. The exception to the above is that some outlets in Monaco supply 127V, although this is rare and being phased out in favour of 230V.

Three-phase at 400V from phase-phase (+/- 10%) is widely available in Europe and in many countries it is mandated for large loads. It is used in nearly all commercial and agricultural installations and is very common in Germanic countries for domestic electric cookers and water heaters. It is used in some domestic supplies in the UK (where the customer has electric water and room heating instead of gas or oil) and is easy to have installed at nearly any location for under £2000. One Tesla customer, Martin Springer from Austria, has reported that his local utility initially insisted that his requirement for 1P 32A be balanced across the three phases. He eventually got a waiver after much hassle, but this will be a recurring problem across the Netherlands, Belgium, Germany, Austria and Switzerland – and potentially other countries where three-phase is the default domestic supply – and is far from ideal. It certainly is an issue for ad-hoc charging on road trips and definitely needs to be addressed for EVs in the EU.

In lieu of Tesla modifying the PEM, it would make sense to produce a charger or converter box that could make full use of three-phase supplies, assuming that the necessary power electronics can be made small enough for a portable device (this is discussed below). There will be a relatively big market for this in the long term.

Across Europe, industrial sockets of the IEC 60309 type (also known as CEE Form, IEC 309, BS 4343, Commando plugs and various other trade names) are a common sight on campgrounds, in theatres, commercial kitchens, industrial and retail locations, farms and some home workshops. They are already used on some charging stations and directly on the inputs of some EVs such as the current Smart ED, Think and NICE cars. Backwards-compatible "CEEplus" sockets with signalling contacts have been used in some German trials, although they are just a stop-gap until the forthcoming IEC 62196-2. This is being promoted by Mennekes and although not yet an agreed standard, it has wide industry support and it is already being used on some charging stations. IEC 60309 are available with ingress ratings up to IP67 (although it appears that IP44 is more common on EVs). All other plug types should be used for indoor use only (unless used with a specially designed socket or charging stations such as the Elektrobay).

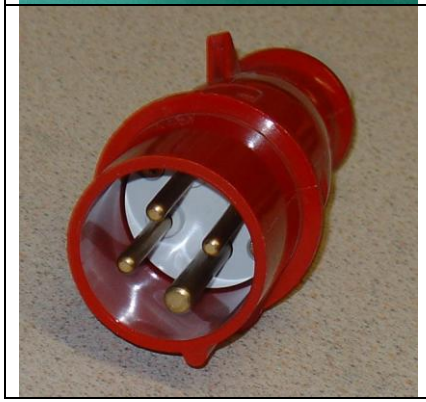
It would also be desirable to get an overnight charging at any location, without higher-power outlets being required. While it is possible to parallel together domestic plugs in a "V" configuration, unlike with the North American system these should always be kept on the same phase. It should be noted that a double (2-gang) outlet cannot be guaranteed to supply double the current of a single outlet. For example, whereas the UK domestic plug is rated at 13A and the ring main it is usually connected to can supply 32A, cheap no-brand double outlets will safely supply no more than 19A *and this is normally marked on the back of the faceplate*, meaning the public don't tend to know this. More than that current and at best the insides tend to melt when overloaded for long periods, at worst a fire hazard. Furthermore, some new installations are using only 20A radial circuits. Any V connector should therefore come with a health warning to always use a separate outlet, preferably on a separate circuit. It would be beneficial to have circuit and phase detection/correction capability and thermal sensors in the plugs to make the practice safer. If in doubt, keep it under 19A.

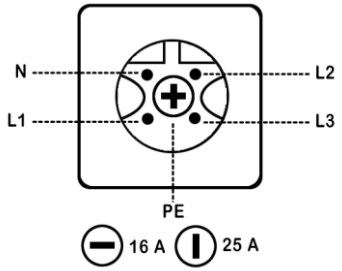
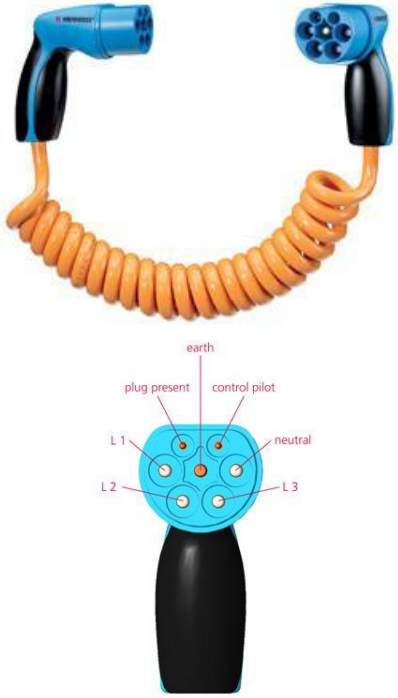
It is worth consulting the latest UK wiring regulations (BS 7671:2008), as these are harmonised with European standards. There is not yet a specific EV section, but they do describe installations for caravans, RVs and mobile units and go into detail such as cable type requirements. This is a paid-for publication, but snippets can be found online.

Nomenclature used for pin configurations is:

1P – 1 live pole/phase, 3P – 3 live poles/phases
N – Neutral
E – Earth / Ground

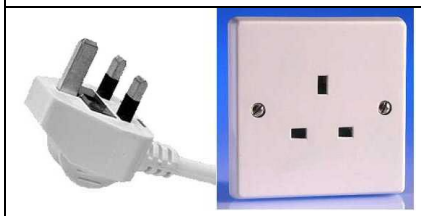
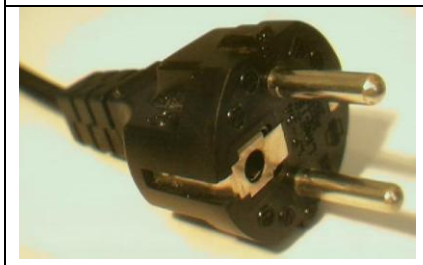
Three-phase Charging

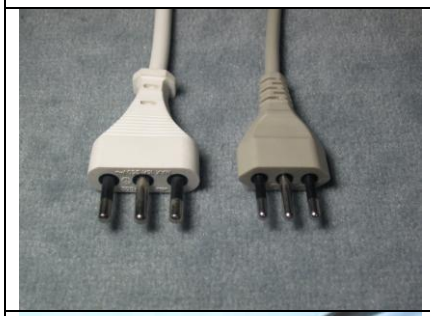
Image	Plug Type	Current	Voltage	Countries in Use	Notes
	IEC 60309 5 Pin (3P+N+E) (Three-phase Y connections)	16A, 32A, 63A, 125A	400V	Europe wide	16 and 32A are common in industrial and commercial premises. Also seen on the Swedish McDonalds charging station. 63 and 125A are mostly found in stage lighting applications. *Martin Springer, a Tesla customer in Austria, was given a 63A version of this outlet when he asked for a circuit to be installed in his garage. The power company initially insisted it was used for a balanced three-phase load but later allowed 32A single phase after much bureaucracy – not ideal and not sustainable. See his photos at www.flickr.com/photos/teslatuning/sets/72157622076085280/* N.B. The four different currents use different physical plug sizes.
	IEC 60309 4 Pin (3P+E) (Three-phase Δ connections)	16A, 32A, 63A, 125A	400V	Europe wide	As above. Note also that 400V @ 32A three-phase is more than sufficient to power a Tesla HPC when converted to single phase 230V (gives 87A at 90% conversion efficiency). N.B. The four different currents use different physical plug sizes.

 	Perilex 5 Pin (3P+N+E) (DIN 49445, DIN 49447)	16A, 25A	400V	Germany, Netherlands	Old standard – gradually being superseded by IEC 60309. Although this can be found in the domestic environment for connecting cookers and water heaters, discussion with German and Dutch friends suggests it is becoming rare. There are many more electric cookers in use in Germany than the Netherlands from reports. 16A has horizontal ground pin, 25A has vertical ground pin.
	Mennekes IEC 62196-2 7 Pin (3P+N+E+ Control+Plug Present)	63A max 32A nom	400V	Europe wide	The proposed new standard for EVs in Europe, this connector will be used on both charging stations and cars. RWE (German electricity utility) and Elektrobay are using this on their three-phase installations already. Broad industry support, but more than a year away from publication. Targeted for "1st Committee Draft" status at IEC by the end of 2009. Control line used for smart grid and billing applications. Pilot signal believed to be the same as SAE J1772-2009. A resistor in the plug denotes the max current for a given cable. The following describe the proposed standard in more detail. http://www.ecs-five.ch/parkcharge/documents/MENNEKES+and+EV.pdf http://www.ecs-five.ch/parkcharge/documents/IEC_62196-2-X%20Proposal%20Troester.pdf IEC Working Group Page: http://tinyurl.com/kv9wk3

Single Phase Charging

Image	Plug Type	Current	Voltage	Countries in Use	Notes
	IEC 60309 5 Pin (3P+N+E)	16A, 32A, 63A, 125A	230V output from 400V 3P supply	Europe wide	16 and 32A are common in industrial and commercial premises. 63 and 125A mostly found in stage lighting applications. By connecting to one phase and neutral, it is possible to connect the single phase charger to a three-phase outlet and obtain 230V, although at high currents this would cause a significant phase imbalance (as with Martin Springer's issue outlined above). Note, this technique does not work at 230V with the 4 pin version. I have seen Tesla using this method to connect the prototype mobile chargers to three-phase outlets at events (they have a made up a small adapter that converts to the blue single phase socket shown below).
	Perilex DIN 49445, DIN 49447 5 Pin (3P+N+E)	16A, 25A	230V output from 400V 3P supply	Germany, Netherlands	Old standard – gradually being superseded by IEC 60309. By connecting one phase and neutral, it is possible to connect the single phase charger to a three-phase outlet and obtain 230V, although at high currents this would cause a significant phase imbalance. 16A has horizontal ground pin, 25A has vertical ground pin.
	Mennekes IEC 62196-2 7 Pin (3P+N+E+ Control+ Plug Present)	70A max	230V	Europe wide	The new standard for EVs in Europe, this will be used on both charging stations and cars. RWE (German electricity utility) and Elektrobay are using this on their three-phase installations. As with previous three-phase connections, can also be used to supply 230V from one phase. Will also be used on wholly single phase charging stations.

	IEC 60309 3 Pin (1P+N+E)	16A, 32A, 63A, 125A	230V	Europe wide	16 and 32A are common in agricultural, industrial and commercial premises. Also used for camp grounds / RV parks (particularly 16A in this application although 32A are known) and appearing on some charging stations. 63A outlets of this type are installed at Tesla's London showroom. 125A is so rare that I have never seen one! N.B. The four different currents use different physical plug sizes.
	BS 1363 3 Pin (1P+N+E)	13A	230V	UK, Ireland, Cyprus, Gibraltar, Malta	The lowest common denominator domestic plug in the UK. It is normally connected to a 32A ring-main and therefore is fused inside the plug at up to 13A. Double outlets are common, but these cannot reliably be used to pull 26A (see explanation in introduction). This plug is also used by the existing single phase Elektrobay charging stations in the UK.
	BS 546 3 Pin (1P+N+E)	15A	230V	UK, Ireland	Older British standard. Once common in households, now almost exclusively used in theatres for lighting rigs. Note: There is a 5A version of this plug that can also be found in Monaco and Portugal. It is not of much interest for EV charging.
	CEE 7/7 2 Pin (1P+N) Both female ground and grounded side pins	16A	230V	Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Latvia, Monaco, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden and Turkey	Europe-wide plug designed to fit both French and German (Schuko) developed sockets and widely adopted across the continent. Note, the French sockets have a male ground pin, whereas the German sockets use two side contact strips for grounding. Note, as this plug fits sockets in all the countries mentioned, it is not necessary to have a separate adapter lead for the French and German systems. This plug is also used by the existing single phase Elektrobay charging stations in mainland Europe.

	Gost 7396	10A	220V	Russia	Very similar to the above, it has smaller diameter pins and so while it can fit the CEE 7/7 sockets, the reverse is not true.
	Section 107-2-D1 3 Pin (1P+N+E)	10A	230V	Denmark	Standard Danish domestic plug, similar to the French type except it has a male earth pin. The CEE 7/7 type will fit the socket, but will be ungrounded. As of July 2008, installation of the French socket is allowed in Denmark (see above). Also, from that date, all sockets must have GFCI protection.
	CEI 23-16/VII 3 Pin (1P+N+E)	10A, 16A	230V	Italy, some old installations in Spain	Standard domestic plug in Italy, the 16A version has the same hole centres as the CEE 7/7, but with a male ground pin in the middle. Therefore a CEE 7/7 can be used in the 16A socket, but will be ungrounded. A variant of the CEE 7/7 socket that has a central grounding hole and figure-of-8-shaped live and neutral holes to take these plugs is starting to be installed in Italy. However, they are not yet common.
	SEC 1011 3 Pin (1P+N+E)	10A	230V	Switzerland, Liechtenstein	Standard domestic plug in Switzerland, it is similar in nature to the Italian plug except the ground pin is offset. The CEE 7/7 plug will fit this socket, but again is ungrounded if used.

A note on three phase converters

I have been researching various three-phase to single phase conversion technologies. The best way to solve the problem seems to be through the use of 3PAC-DC-1PAC solid state rectifier/inverters. Initial investigations lead to unsuitable products that were bulky (around 100kg and the size of a washing machine) for 10-15kW output.

Ongoing investigations have found that Mitsubishi Electric manufactures three-phase inverters for motor drives that are significantly smaller and perform a very similar function, which could in theory be adapted through software or small hardware modifications. The 7.2kVA FR D-700 series measures 108x128x165mm and weighs 1.5kg and the largest 23kVA FR E-740 series measures 220x260x190mm and weighs 5.9kg. Thermal dissipation is low (180-500W respectively). Prices range from £700-£1000.

The full FR E-740 manual can be found here: http://www.acpd.co.uk/sei/s/1488/mitsubishi%20e700%20series%20manual.pdf

This shows that the challenge of even a 70A portable converter is not insurmountable – and new components such as SiC diodes may reduce size and heat loses further.

In Summary

I would recommend that kits for each country are supplied with the local domestic plug in addition to 16A and 32A IEC 60309 plugs. If a lightweight, portable three-phase version of the charger can be developed, this would be a real boon and allow for rapid charging in a lot more places. However, failing this, it would be useful to be able to draw single phase power from a three-phase outlet at both 16A and 32A, where regulations allow.

Therefore, the basic single phase kit would consist of 5 adapters: local domestic, 16 and 32A 3 pin blue and 16 and 32A 5 pin red IEC 60309 plugs wired for single phase. Once a source of Mennekes EV plugs is found – and assuming the IEC 62196-2 standard establishes itself – these should also be included by default. If a three-phase charger is made, then the 4 pin version of the 16A and 32A IEC 60309 plugs should also be added, with these and the 5 pin variants wired for three-phase use. Where a country is in transition, or for other reasons two systems are in use, both domestic plugs should be supplied.

It is recommended to draw a current of 1 or more amps under the rating of an outlet (e.g. 12A on a UK domestic 13A plug, possibly 30A on a 32A IEC 60309 connection).

Optional extras could be offered for those sockets the customer is less likely to need: This could include the 63A version of the IEC60309 family (3, 4 and 5 pin versions – although more feedback on what customers like Martin are getting installed from their utilities would be helpful) and other locales' domestic plugs. The latter might be useful for those living near a border (e.g. customers of the Geneva store will be travelling between France and Switzerland, and customers of the Monaco store could find themselves in France or Italy).

I'm not convinced that the Perilex plug is needed – it seems to be very much on the wane. Neither am I convinced that the 125A IEC60309 plugs are needed, unless there is demand for mobile use of the HPC or a customer only has access to a 125A outlet. The BS546 plug is also unlikely to have many takers. We can monitor demand for these.

"V" adapters could prove very useful, allowing for the caveats I described above. The best option would be to develop circuitry to allow them to be used safely – including phase detection and temperature sensing for shutdown – in fact this may be a requirement. I will consult the wiring regulations further. These would allow for an overnight charge from domestic sockets and go some way to answer the EV critics regarding "any location" charge times.

A health warning should also be given not to use the kit with common travel adapters. This is because some combinations would allow an overload – for example adapters exist to allow the CEE 7/7 to be used in both UK and Swiss outlets, but in these instances the charger would draw up to 16A from outlets rated at 13A and 10A respectively. It should be stressed that the correct pigtail should be used.

Note, for equipment sold into Europe there are various directives and conformity requirements. Attention should be paid to the CE mark, e mark (for cars), RoHS directive and WEEE directive. The latter two apply specifically to electronics, however there may be waivers for low volume products. This needs to be checked.

David Peilow
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