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SELFPLUG®: conductive automatic charging for electric vehicles

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SELFPLUG® is a conductive automatic charging solution for electric vehicles, based on a patented magnetic technology for guiding and connecting. The solution consists of a Ground Unit with a magnetic socket and a Vehicle Unit with a magnetic plug. The magnetic plug automatically moves to the magnetic socket thanks to a guiding and centering electromagnetic patented technology. It is compatible with existing or brand new 100% Electric Vehicles (EV), Plug-In Hybrid Electric Vehicles (PHEV) and autonomous vehicles. SELFPLUG® allows an easier, faster and safer automatic charging than induction-based solutions or other conductive solutions.

Keywords: automated, charging, conductive charger, mass market, V2G (vehicle to grid)

1 Introduction

Automatic charging of parked electric vehicles is on its way to become a mass market solution that not only improves customer experience but also unlocks fantastic value in several pioneering energy and mobility fields.

1.1 Unlocking value with electric vehicle automatic plug-in for conductive charging

Electric vehicles automatic charging is increasingly perceived as a necessary customer experience improvement, which motivated its early development. SELFPLUG® eliminates the customer pain point of plug-in and charging, facilitating the commercial development of electric cars to a larger audience. However, its greatest asset now lies in the value that it unlocks in other areas.

1.1.1 From improving customer experience…

The first demands for electric vehicles automatic charging solutions came from car manufacturers looking to improve the customer experience. Most users who are aware of this technologic development support this strategy, which is explained by the fact that electric vehicles charging is one of the main customer pain points and that automatic charging contributes to the innovative and almost futuristic image of electric vehicles. With automatic charging, electric vehicle drivers no longer have to worry about plug-in, they are confident that their car will be charged when they need it. It is a safer, more convenient, more hygienic and more time-efficient way to approach electric vehicles charging.

In order to develop automatic charging, car manufacturers first turned to stationary contactless inductive charging, a technology that has benefited from a growing positive perception over the last few years. However, they were quickly faced with the limits of induction in terms of cost and customer experience: inductive solutions are more expensive and usually require a costly installation ; they require the driver to park with a very high precision of 1cm to 5cm ; they must include presence detectors that interrupt the charging when live beings are in a 5m radius because induction radiates high frequency waves that can damage health ; their energy efficiency is limited as some of the power is lost while charging. That is why car manufacturers are now turning to conductive automatic charging solutions which offer a better and safer customer experience, easier set up and parking, and better energy efficiency at a lower price.

1.1.2 …to unlocking fantastic value in pioneering energy and mobility fields

This shift from inductive to conductive technologies opens huge opportunities in the field of “vehicle to grid” (V2G), as conductive plug-in enables 100% efficient bidirectional charging. With the vehicle owner’s approval and under the conditions the vehicle owner agrees to, this will allow smart grid operators to use electric vehicles to store electricity when electricity production is higher than demand, and to restitute some of the power back to the grid when electricity demand is higher than production. Of course, V2G enabled smart grid solutions will also ensure vehicles are properly charged when they need to be driven.

V2G will bring grid operators the flexibility they need to provide more power without investing in new electricity production capability, and even to reduce the number of electricity production facilities. This will allow grid operators to keep electricity prices low, which will benefit to the general public.

V2G will also support the development of sustainable energy sources such as solar panels and wind turbines. When conditions are optimal (windy and sunny for example), the electricity produced in excess can be stored in vehicles. When conditions are sub-optimal, (no wind, cloudy), the electricity that is available in vehicles that are plugged in can be used to supply the grid and make up for the electricity offer/demand gap.

Finally, V2G will transform electric vehicles into an attractive investment for users: as they bring flexibility to grid operators, users will benefit from discounted electricity rates and may even receive financial incentives to own and connect an electric vehicle.

The value of V2G is proportional to the number of vehicles that are connected to the grid. Without automatic plug-in, a large number of vehicles would not be plugged in due to the fact that users can forget to plug them in or consider that is it not necessary to plug them in every day. Conductive automatic plug-in will maximize V2G value by guaranteeing that all vehicles that are not being driven will be plugged in and ready for electricity demand/response balancing.

This V2G value cannot be achieved using today’s inductive charging solutions as they do not allow bidirectional charging for demand/response scenarios and are not 100% energy efficient.

V2G is not the only scenario in which automatic conductive plug in turns electric vehicles into attractive investment supporting sustainable development. For example, instead of passively occupying space on a parking space, plugged-in vehicles could actively run embedded depollution systems to clean the air. Automatic conductive plug-in will ensure that equipped vehicles are cleaning the air whenever they are not being driven. As a public well-being solution, it could justify financial incentives to own and plug in electric vehicles.

Finally, there is the question of electric autonomous vehicles and electric self-parking vehicles: in order to be truly autonomous or self-parking, they must plug-in on their own. Nowadays, inductive solutions are not adapted to this use as parking with a 1cm to 5cm precision is a challenge for autonomous vehicles. Conductive automatic charging with less precision needed is a better match and more energy efficient.

1.2 A mass market solution

By the end of 2018, the global plug-in vehicles population was expected to reach approximately 5.4 million [1] with 2.1 million plug-in vehicles forecast to be delivered in 2018: a 64% increase compared to 2017. Global electric vehicle sales are projected to reach 10,79 million units by 2025. [2]

95% of electric vehicle charging happens at home and at work [3], while only 5% is done using public charging infrastructure. SELFPLUG® primarily targets homes and workplaces and should therefore have a strong impact on the fast-growing electric mobility market.

2 State of the art

2.1 Inductive solutions

A small number of companies develop contactless inductive automatic charging solutions for electric vehicles, some of them in a close relationship with car makers.

Inductive solutions led the way in the field of automatic charging. They use a ground pad that is set on the parking space or embedded in the floor and connected it to an electrical box, which requires a costly installation.

To charge, the electric vehicle must be parked over the ground pad with a precision of 1cm to 5cm. It is a very difficult operation for a driver, and nowadays it is also a challenge for autonomous vehicles.

Once the vehicle is properly parked, charging can start. Charging automatically stops when the vehicle moves away from the ground pad.

Inductive charging is not 100% energy efficient. A substantial amount of power is lost while charging, which is a financial issue for users and a global environmental issue.

Electric vehicle inductive charging solutions use wireless power transfer systems which raise safety issues. Electric vehicle charging requires high power, which increases human and animal exposure to potentially harmful time-varying electromagnetic fields [4]. Furthermore, the wireless power transfer system electromagnetic field may cause the false operation of electronic devices such as pacemakers. The companies that develop these electric vehicle inductive charging technologies are working on foreign object detection and living object detection in an attempt to protect humans - particularly young children who may stray under the car – and animals. This enables the system to interrupt the charge when live beings are present or when foreign objects may create safety issues. Charging can therefore be interrupted for long periods of time, resulting in electric vehicles not being charged with enough power, and concerns remain regarding the safety of inductive automatic charging for electric vehicles.

Existing inductive charging solutions for electric vehicles do not provide bidirectional charging and are therefore not V2G ready.

2.2 Conductive solutions

Three types of conductive automatic charging solutions are under development by a small number of companies. Unlike inductive solutions, they are 100% energy efficient, they usually allow bidirectional charge, they do not require precise parking and do not necessarily create safety concerns. They are usually less expensive than inductive solutions.

2.2.1 Solutions using a robot

Most conductive automatic charging solutions use a robot to connect the car. The robot is a flat unit set on the parking space or embedded in the floor and connected to the power or to a wall box. When the car is parked over the ground unit, a wireless signal enables the robot to locate the plug that is embedded under the car. The robot then unfolds and lifts a socket in the direction of that plug in order to connect. Once the robot is connected to the car, charging can start. When the driver turns the vehicle on, the robot unplugs and folds back in its original flat position.

Charging robots have a number of advantages over inductive solutions. However moving parts may create safety concerns for animals and young children, and uneven ground or incidents may cause damage to expensive parts of the robot.

2.2.2 Solutions using multiple contact pins

Another less frequent solution uses a broad ground unit that is covered with contact pins. When the car is parked over the ground unit, a wireless signal enables the car to unfold a connector in a vertical movement. The connector covers some of the contact pins. The contact pins that are covered by the connector activate and charging can start. When the driver turns the vehicle on, the vehicle folds the connector back in.

These solutions are less costly than inductive solutions and charging robots. However, even though the only contact pins that activate are the ones covered by the connector, there is no physical protection against electrical risk, which creates safety concerns. On uneven ground, connection may be difficult. Finally, the contact pins are exposed to water, dust, car wheels, foreign objects and other factors that could prevent a successful and safe connection and charging.

2.2.3 Solutions using magnetic and electromagnetic guiding and connection

SELFPLUG® stands alone in this third category. We detail the SELFPLUG® concept in the next paragraph.

3 The SELFPLUG® solution

In order to provide conductive automatic charging of electric vehicles, SELFPLUG® uses a patented magnetic technology to guide and connect a magnetic plug to a magnetic socket. The SELFPLUG® shown in Figure 1 has a number of advantages over inductive automatic charging solutions and other conductive automatic charging solutions. It is easy to set up and transport. It is 100% energy efficient and allows bidirectional charging. It does not raise any safety concern. It can be used on uneven ground and is resistant to water, dust, ice, car wheels and other environment challenges. In case of incident, there is no expensive part that can be damaged. It is less expensive than inductive solutions and conductive charging robots.

Figure 1: SELFPLUG® on a Renault ZOE

3.1 Vehicle unit

The vehicle unit show in Figure 2 is embedded under the electric vehicle as an original equipment or as an aftermarket accessory. It consists of a magnetic plug, a power cable, an uncoiler/coiler and a protective lid for the magnetic plug that is closed when the vehicle is not plugged in.

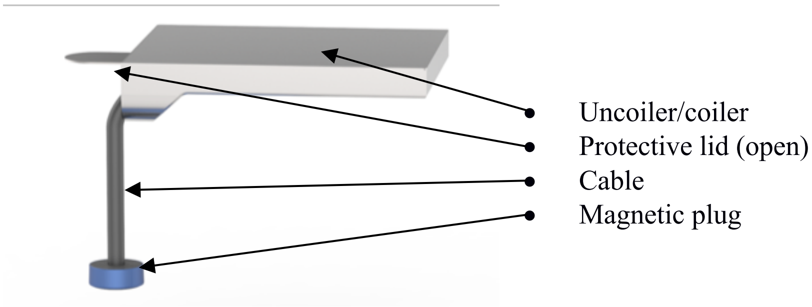


Figure 2: SELFPLUG® vehicle unit

Its dimensions were studied to easily fit under any car.

3.2 Ground unit

The ground unit shown in Figure 3 and Figure 4 is set on the parking space and plugged in a standard wall socket or in a wall-box outlet. It can easily be transported from one parking space to another, in the trunk of the vehicle for example. If necessary, it can be securely bolted to the ground. It consists of a magnetic socket, an electromagnetic guiding system, a bevel and a protective lid for the magnetic socket that is closed when the vehicle is not plugged in.

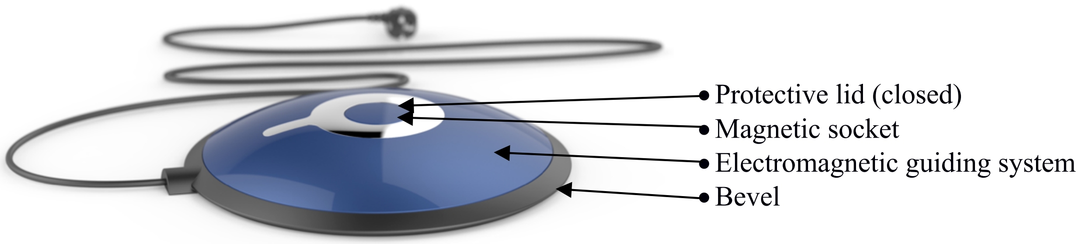


Figure 3: SELFPLUG® ground unit with closed protective lid

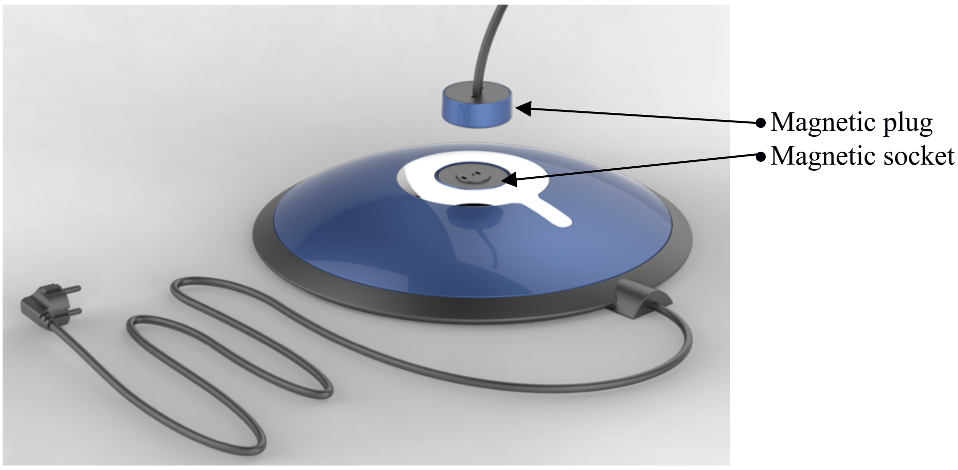


Figure 4: SELFPLUG® ground unit with open protective lid

The ground unit diameter is 60 cm. The ground unit can guide the magnetic plug in a diameter of 50 cm. This diameter was found by a leading car maker to be sufficient to allow automatic charging without requiring precise parking. We are not allowed to disclose the name of the car maker.

Thanks to the dome shape of the ground unit, foreign objects and liquids that may land on the ground unit slide or spill toward the ground. This ensures these objects and liquids will not interfere with the automatic plug-in process.

3.3 Automatic charging process

SELFPLUG® automatic plug-in and charging 3D rendering in video: https://youtu.be/1fMxRe3jPEk .

SELFPLUG® automatic plug-in and charging with an Aixam Mega: https://youtu.be/_6hCjwAj9u4 .

3.3.1 Ground unit set-up

The user sets the ground unit on the parking space and plugs it in a standard wall socket as shown in Figure 5 or in a wall-box outlet as shown in figure 6.

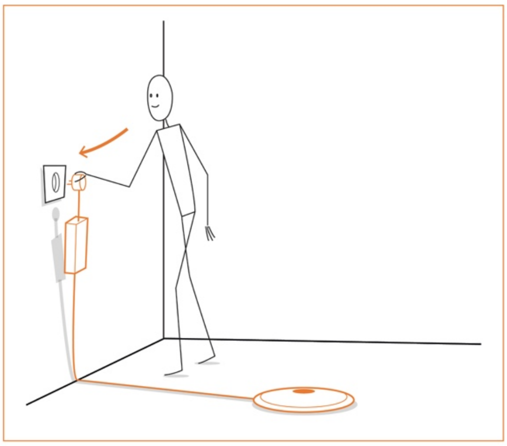


Figure 5: SELFPLUG® set up on standard wall socket

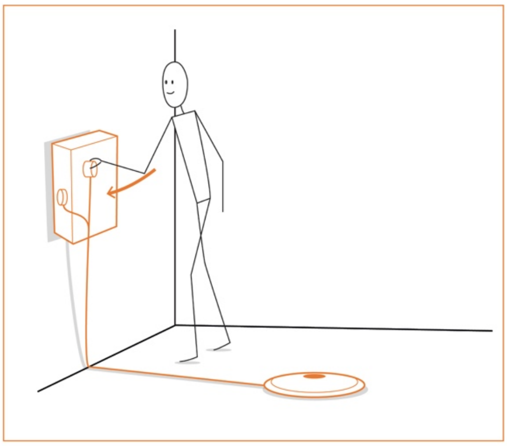


Figure 6: SELFPLUG® set up on a wall box

3.3.2 Parking

The driver parks the car in the parking space as usual, with no precision required. The location of the ground unit on the parking space determines whether the driver should park forward of backwards.

3.3.3 Ground unit and vehicle unit pairing and authenticating

As the vehicle approaches the parking space, the ground unit and vehicle unit wirelessly pair and authenticate as shown in Figure 7.

A sound or visual signal can be used to inform the user of a successful pairing and parking, as shown in Figure 8.

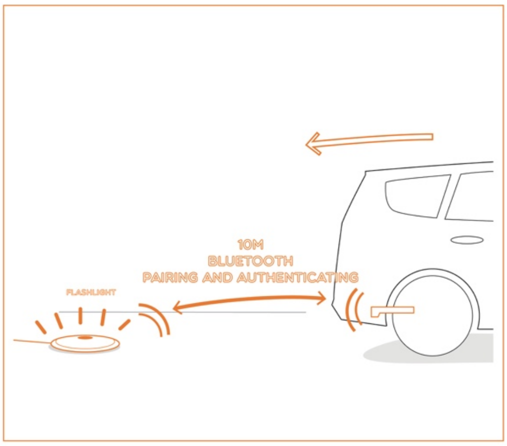


Figure 7: SELFPLUG® wireless pairing and authenticating

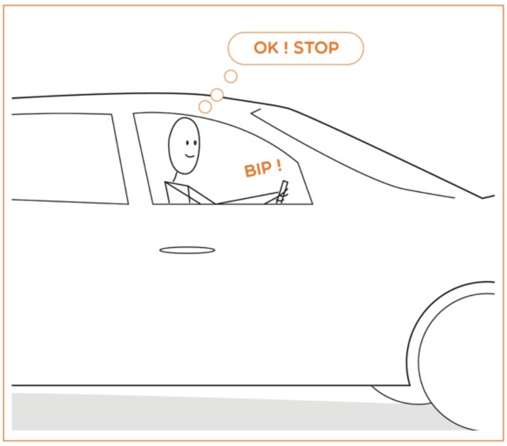
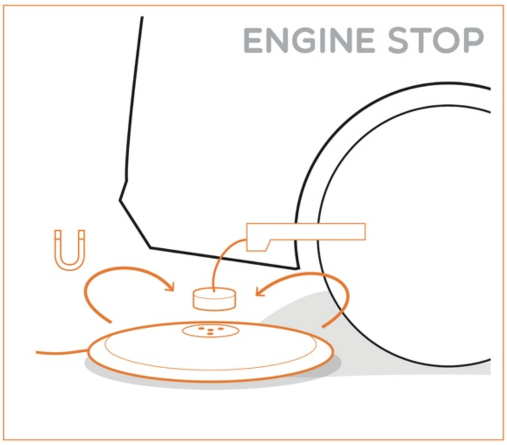


Figure 8: SELFPLUG® parking signal

3.3.4 Automatic plug-in

After a successful pairing, authenticating and parking, when the engine stops, the vehicle unit lowers the magnetic plug in a vertical movement, within the 50 cm diameter of the electromagnetic architecture of the ground unit.

The lowering of the magnetic plug triggers the electromagnetic guiding system which guides the magnetic plug to the magnetic socket, as shown in Figure 9. The magnetic plug and magnetic socket automatically connect and charging can start. A sound or visual signal can be used to inform the user of a successful plug-in, as shown in Figure 10.



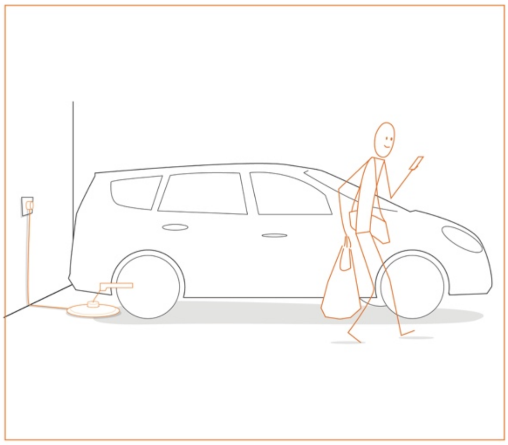


Figure 9: SELFPLUG® automatic plug-in (1)

Figure 10: SELFPLUG® automatic plug-in (2)

3.3.5 Charging

Charging happens immediately or later, depending on the conditions chosen by the user to benefit from the best electricity rates or, in a V2G scenario for example, on the conditions the user and smart grid operator agreed on. Users can use their smartphone to remotely monitor charging.

3.3.6 Automatic unplugging

When the engine starts, the vehicle unit coils the magnetic plug back in and covers it with the protective lid. The strength of the pull unplugs the magnetic plug from the magnetic socket as shown in Figure 11. A sound or visual signal can be used to inform the user of a successful unplugging.

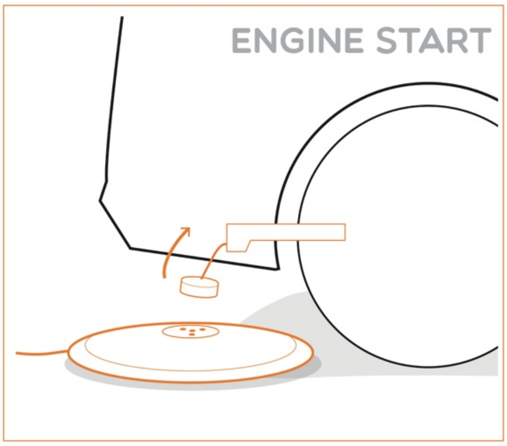
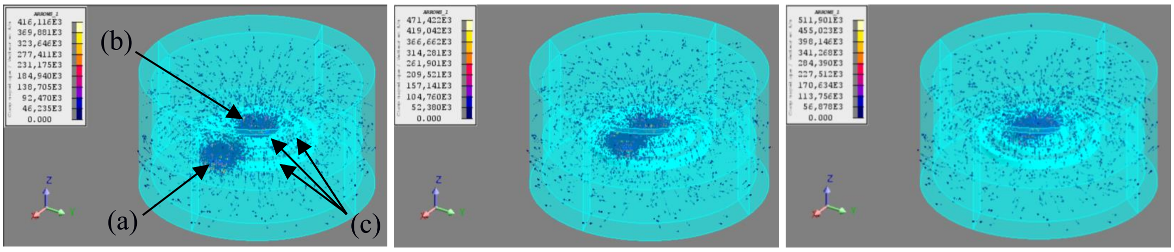


Figure 11: SELFPLUG® automatic unplugging

4 Models, tests and work in progress

4.1 Magnetic guiding simulation with FLUX

Figure 12 is a FLUX model that shows the ground unit guiding the magnetic plug to the magnetic socket.



Stage 1. Stage 2. Stage 3.

Figure 12: Magnetic guiding FLUX model during the guiding process

It includes the plug's magnetic architecture (a), the socket's magnetic architecture (b) and 3 concentric coils (c) activated sequentially as follow: larger coil (Stage 1), intermediary coil (Stage 2) and smaller coil (Stage 3).

4.2 Single-phase SELFPLUG®

The first functional prototype was a single phase SELFPLUG®. To date, it has been tested with 3 different types of vehicles.

The first tests were done in April 2018 using the commercial vehicle shown in Figure 13: an Aixam Mega [6]. A video is available on https://youtu.be/_6hCjwAj9u4 .

Figure 13: SELFPLUG® on an Aixam Mega

In November 2018, a Renault ZOE [7] was equipped with SELFPLUG® by students of the Emile-Béjuit professional high-school, specialized in automotive. This integration is shown in Figure 1, and a video is available on https://youtu.be/tBC1cd96xiM .

In December NAVYA equipped the Autonom Shuttle [8] shown in Figure 14 with SELFPLUG® to perform tests. A video is available on https://youtu.be/1lt-0Q_b5cI . According to the NAVYA engineer in charge of this project: "*The results are very positive. In a straight line the positioning is precise, the pairing between the plug and the ground unit works every time.*"

Figure 14: SELFPLUG® on a NAVYA Autonom Shuttle

SELFPLUG® has also been tested under various conditions using the custom-made test bench shown in Figure 15.

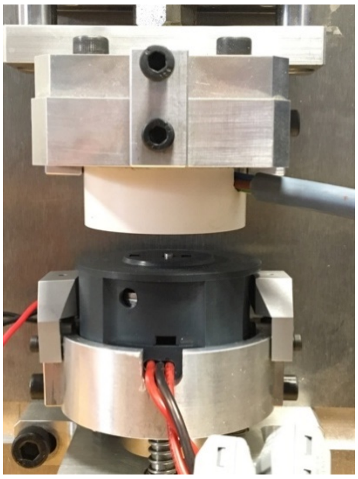


Figure 15: SELFPLUG® test bench

4.3 Three-phase SELFPLUG®

To meet the needs of the vehicle manufacturers we work with, we are now developing a three-phase SELFPLUG® with standard EV contacts CP &PP. Its magnetic architecture and connecting process had to be revisited to take three-phase challenges into account, which led us to develop a new innovative magnetic connection concept that strengthens the intellectual property of SELFPLUG®.

Developments are under way to deliver a three-phase SELFPLUG® prototype to a world-leading car maker, in partnership with a Tier 1 equipment supplier.

5 Conclusion

We aim to achieve all single-phase and three-phase SELFPLUG® developments in 2019. Thanks to the partnerships we are building with world-leading companies in the field of clean mobility, SELFPLUG® should be available as an aftermarket accessory for existing vehicles in 2020 and should be sold as an original equipment on brand-new vehicles in 2022.

As smart grid and V2G systems come into play over the next few years, the value of SELFPLUG® for the various stake-holders – vehicle owners, grid operators, vehicle makers – will increase, supporting its growth. This growth will also be supported by the development of new applications that activate the potential of parked electric vehicles at the condition that they are plugged in at all time, such as depollution systems

Even though SELFPLUG® primarily addresses charging of personal vehicles at home and in work places, which represent 95% of charging, there are other markets SELFPLUG® can address over the next few years to diversify its outlets.

The first is professional electric vehicles fleets, which are looking for innovative electric vehicle plug-in solutions to meet challenges that are specific to their business. For example, as the vehicles are shared, drivers are more liable to forget plugging them in after driving them, resulting in the vehicles not being available for the next driver. Automatic charging will ensure that all vehicles are properly charged when needed. Another example is the European Seveso listed sites: vehicles must all be parked backwards to ensure a swift evacuation in case of emergency, but some vehicles have a plug at the front. This forces companies to invest in costly power cable installations to ensure a safe plug-in while respecting the Seveso Directive. SELFPLUG® would be a less expensive, more convenient and safer solution.

Another market is public charging infrastructure, which represents 5% of charging. Today public charging infrastructure use bulky electrical boxes that take up space on sidewalks and parking lots. Electric vehicles are plugged in manually using long cables that must be stored in the trunk of the vehicle and force vehicle user to find ways to avoid dropping the cable directly in the gutter, as shown in Figure 16

Figure 16: Public charging infrastructure that could be improved with SELFPLUG®

A SELFPLUG® embedded in the parking space would not waste any space and would provide a much better customer experience.

Last, but not least, autonomous vehicles need automatic charging solutions to be fully autonomous. We are already working with autonomous vehicle manufacturers to integrate SELFPLUG® in autonomous vehicles as an original equipment.

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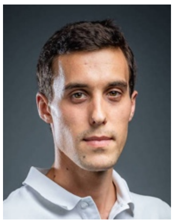
[5] SELFPLUG® 3D rendering with: https://youtu.be/1fMxRe3jPEk

[6] SELFPLUG® demo with an Aixam Mega: https://youtu.be/_6hCjwAj9u4

[7] SELFPLUG® demo with a Renault ZOE: https://youtu.be/tBC1cd96xiM

[8] SELFPLUG® demo with a NAVYA Autonom Shuttle: https://youtu.be/tBC1cd96xiM

Authors



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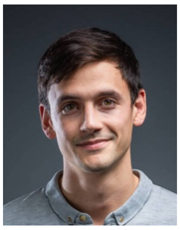

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