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# AC or DC fast charging solutions?

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## Abstract

Standard charge for electric vehicle is an AC charge for some kilowatts. For fast charging, DC charge with an external charger is frequently developed. The investments for the deployment of DC chargers can be supported by car manufacturers as TESLA or by collectivities.

The major aim of this paper is to present the results and conclusions of two projects about the question of AC or DC fast charging solutions. The first one, ELLiSup (bus application) is a national project in France, the second project is ESPRIT (electric vehicles application), an H2020 European project. The second goal is to compare the different existing fast charging solutions and to propose new potential solutions for the next years.

## 1. Context

The CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives) is an energy technological research center in France dedicated to research and development in two domains: nuclear energy and renewable energy. Some of the research interests in Grenoble LITEN institute from CEA are hybrid and electrical vehicles. All the value chain is concerned for the research activities from raw material to battery systems integration in the applications: materials for Lithium ion accumulators, accumulator and battery packs design, battery management systems, electric vehicle integration, hybridization with fuels cells and monitoring of vehicles.

## 2. Projects experience return

### 1.1 ELLiSup project (DC charging station)

ELLiSup [2] was a national research project in France to develop notably a pure electric bus with fast charge at the end of the line. The main idea of the concept was to limit the embedded battery size thanks to a 5 minutes "fast and partial" charge of the battery at the end of the line. This concept allows embedding only 1 ton of battery instead of 3 tons for classical solution. To test this concept, a 350 kW station has been studied and realized.



**Fig. 1:** ELLiSup project

Regarding power, only two cables (DC voltage) are connected to the bus thanks a pantograph.

The charger is connected to the AC grid through a high voltage transformer (15kV/400V), filter, and nine buck converters in parallel to charge the bus. The power electronics cabinet (Fig.2), located in a charging station is constituted of 9 bidirectional DC-DC converters set in parallel.



**Fig. 2:** Power Electronics Cabinet

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urban area where ground surface is expensive.

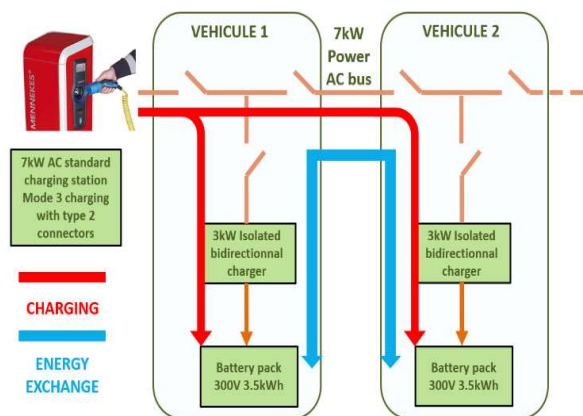
**Fig. 4: ESPRIT concept**

Energy exchanges are possible between vehicles (Fig. 6) to have more energy in the first vehicle of the train, because it will be the first vehicle for the future run.



**Fig. 5:** ESPRIT from the concept to first vehicles

Only one charging station is used to charge the complete road train. Initially, at the beginning of the project, DC charging has been chosen. The initial concept was to charge the train on existing 50 kW DC charger for cars. For the deployment of the solution, the cost of the standard DC fast charge station appears as a limitation for cities who wanted only to use the existing AC charging stations and not to pay additional DC charging stations.



**Fig. 6:** Multi vehicles AC charging solution

Electric architecture of the vehicle were modified to embed an AC charger on the vehicles for connecting on existing AC plugs.

Activities about electric architectures for cars and car in train are still in evolution in this project, but AC charge is definitively chosen because of the much lower infrastructure costs.

### 3. Standard and fast charging

#### 3.1. Main questions about charging

To choose the right and best charging solution, there are several questions to address:

- Is fast charging really necessary for the application and if yes which level of power do we need exactly?
- Is insulation required?
- Is bidirectionality required?
- What kind of intelligence do we need? (power adaptation depending on battery and electricity network capabilities)
- And finally what is the best solution: AC or DC input?

In the following chapters, we will mainly deal with the last question concerning AC or DC inputs.

#### 3.2. Standardization of charging

Electric vehicles charging solutions are split in four modes ([4],[7]). The main differences concerning input, power, communication and protections are reported in the following table and graph on Fig. 8.

| Charging MODE          | MODE 1                        | MODE 2         | MODE 3    | MODE 4        |
|------------------------|-------------------------------|----------------|-----------|---------------|
| AC or DC input         | AC (1 or 3 ph)                | AC (1 or 3 ph) | AC (3 ph) | DC            |
| Max power (kW)         | 11 kW                         | 22 kW          | 43.5 kW   | ~ 150 kW      |
| Embedded charger       | yes                           | yes            | yes       | not mandatory |
| Communication          | no                            | yes            | yes       | yes           |
| Controlled             | no                            | no             | yes       | yes           |
| Integrated protections | no                            | yes            | yes       | yes           |
| Charge speed           | slow                          | standard       | fast      | ultra fast    |
| Comments               | not allowed in some countries |                |           |               |

Fig. 7: Different charging modes

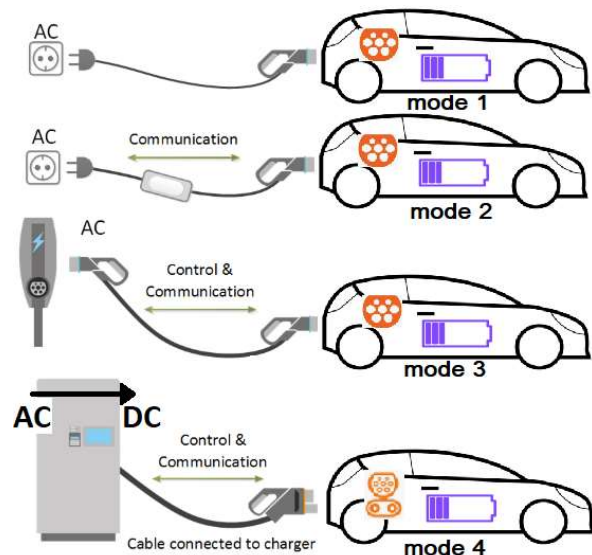


Fig. 8: Different charging modes representation

#### 3.3. Standard charging

Standard charge of electric vehicles is usually based on an isolated embedded charger of some kilowatts. For example, single phase 3kW charger can be used for a standard plug connection (mode 1 or 2) or 22kW three phases charger for a wallbox plug connection. For standard plug connection, an interface is used inside the cable to provide additional protections. For wallbox the interface electronic is included in the wallbox. The main function is the control of the earth connection link of the vehicle.



Fig. 9: Mennekes cable

This electronic communicates with the vehicle by the cable. A contactor isolates the plug from the main and is activated only after some safety controls: vehicle detection, cable earth connection to the vehicle, earth current level.

The value of the maximum power available from the network is transmitted to the embedded charger in order to adapt the charging current at the right level.

The IEC 61851-1:2000 standard describes the J1772 protocol.

Classically, standard chargers are isolated ones to minimize the part of the vehicle connected to the grid. Then the over-voltages and spikes that could occur are not directly transmitted to the battery, the powertrain inverter and auxiliaries. Besides, common mode Y capacitors of EMC filters connected to powertrain inverters and auxiliaries do not create earth line current. The value of these capacitors are not anymore limited by earth connection maximum current constraint.

### **3.4. Fast charging**

For fast charging, the order of magnitude is twenty to hundreds of kilowatts to charge the battery in some tens of minutes which is in accordance with Lithium-ion batteries capacities. For example, the Li-ion batteries handheld power tools have a charging time of 20 to 30 minutes. An important question is the impact of the rate of charge on battery lifetime. This impact is very dependent of the temperature. It is well known than Lithium-ion accumulator lifetime decreases at high temperature, especially in the range above 35-45°C. But also charges at low temperature have a big impact. In battery domain low temperatures start below 0°C or +5°C depending on the technologies [1]. Since the battery temperature rises when charged at high power and To avoid lifetime problems, thermal management systems are frequently used to adjust the temperature during fast charging sequences.

#### **3.4.1. Standard DC fast charging**

For DC current fast charging (mode 4), the two battery poles are connected to the plug or to another connection contacts as pantographs for buses or trucks.

The additional components on vehicles are only contactors and safety electronic functions. All the main functions are in the charging station. It's necessary to provide a regulated DC current limited to the maximum battery one. The maximum battery current depends on the

technology, state of charge and temperature of the battery. This information is provided by the BMS (Battery Management System) to the charging station. Charging station are also usually isolated. The output current is isolated from the main in order to be adapted with all the vehicles, independently of the insulation performances and filter capacitors on the vehicle side. Main's over-voltages and spikes are limited by the electro technical solutions or power electronics components installed on the primary side of the transformer, so the secondary voltage is protected.

The advantage of this solution is that the fast charger is outside of the vehicle, thus there is no overweight and over-cost to embed inside the vehicle. But the main drawback is the cost (ratio between 5 and 10 between AC and DC charging station) of infrastructure which has to be supported by collectivity or private companies.

Because of all the power electronic, the reliability is much lower with greater impact. The failure of the charger affects the charging station and all the vehicles around, and not only one vehicle. Another drawback, less important but still significant, is the weight of the plug. In fact with three poles (AC solution), it is much easier to transfer high currents than with two poles (DC solution).

#### **3.4.2. Standard AC fast charging**

With standard AC fast charging (mode 3), the charger is embedded inside the vehicle, to provide the DC controlled and regulated current to the battery. The main drawback is the high power converter embedded inside the vehicle, increasing cost and weight.

AC fast charging is the standard solution for fast charge within the range of some tens of kilowatts. Classical solution is a 3 phases AC to DC 22kW isolated embedded charger. .

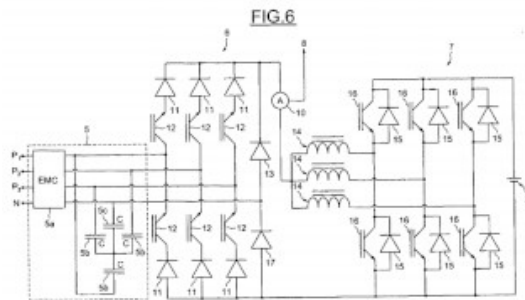
#### **3.4.3. Other AC fast charging solutions**

Since almost ten years, car manufacturers and their suppliers try to find solutions in order to perform fast charge without integrating a high power charger with high cost. The main idea is to re-use the inverter and motors inductances to provide a high power charging function. Indeed, the maximum power of the inverter is usually in the range of what we need for fast charging.

Thus it is a very attractive solution because it could allow to remove a high power converter. Nevertheless, despite Renault which has already integrated this kind of solution, it seems that on the market there is no other electric vehicles manufacturers making the same kind of choice.

### Renault solution

In ZOE electric car from Renault [3], the charger is a not isolated one. Power electronics charger is based on the reused of a part of the inverter and electric motor of the power train. There is no communication on this patented technology used. The electrical architecture seems to be based on a controlled rectifier with IGBT in series with diodes to supply the three motor inductances by the common point of this inductances, and the IGBT bridges of the inverter used as a boost. The only added part to provide the global charging function is the controlled rectifier.



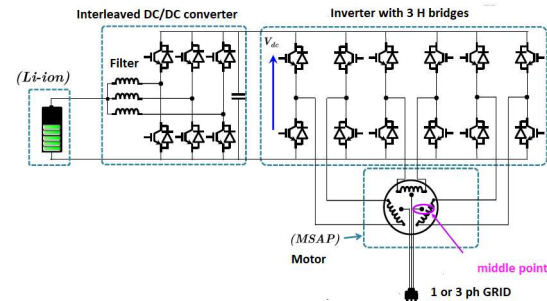
**Fig. 10:** Renault patent [3] - Non isolated charger with sharing of inverter bridge

One first drawback of this circuit is capacitors on the alternative input. At low power, for example for a 3 kW charge, the reactive current in the input capacitors is important. Because of the wide power range of the converter a poor efficiency at low power was observed on the first generation of the ZOE. For the second generation of the vehicle, maximum charge power decreased from 44 kW to 22kW, which improved its performances during lower power charge.

### Valeo solution (SOFRACI structure)

Fig 11 shows the VALEO solution. If the number of switches rises and the motor design is complicated due to middle point on motor

inductances, it offers some advantages. The structure provides a better power factor correction thanks to the full bridge and is bidirectional. This last point is a mandatory requirement for the next years to reuse the batteries of the cars for energy storage, for V2G and V2H applications.

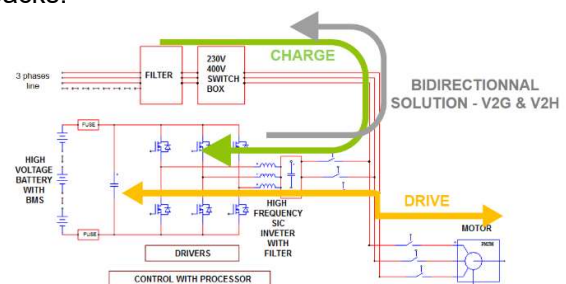


**Fig. 11:** Valeo patent – SOFRACI structure - No isolated charger with sharing of inverter bridge [5], [6]

### **3.4.4. New proposals for fast charging**

In the last chapter, two solutions, which use inverters in traction and charging mode, have been presented. These solutions are very interesting because they allow the re-use of power electronics components. But the common mode parasitic capacitances of the motor create high level of electromagnetic perturbations that are difficult to manage.

In CEA laboratories, a simple single stage solution is currently studied. Motor inductances aren't re-used which decreases drastically the parasitic capacitance but also makes the use of an added filter mandatory. With SiC inverter the size of this filter can be reduced. Contactors are also necessary for isolation of the motor or the battery pack. It is a very simple one but which obliges to work with higher voltage battery packs.



**Fig. 12:** Bidirectional high voltage inverter used both in traction and charging modes

This last presented solution is also very interesting but various disadvantages have to be overcome. The BMS is bigger due to higher voltage; thermal and aging impacts of high frequency currents in the battery have to be precisely evaluated; electromechanical contactors to disconnect the battery to the inverter seem to be necessary.

Nevertheless, if all drawbacks are taken into account and if intelligent mitigation solutions are implemented, we have a very attractive single stage converter, which simplifies drastically the global architecture and reduce the global cost of electric vehicle with a bidirectional charger.

## 4. Conclusion

Standard charge is based on AC charging embedded in vehicle, mainly by isolated chargers.

Direct Current charge is simple from vehicle side but the cost of the charger is transfer to an external infrastructure. Then, the question is to know who wants to pay this cost and to provide the maintenance for years.

For our point of view, in most of applications, the cost of those infrastructures will drive vehicle manufacturers in the direction of AC fast charging.

This conclusion becomes much more relevant if power electronics community finds efficient solutions to combine inverter and charger. Until now, only few solutions have been tested but they were not completely accepted as standard for electric vehicle. The challenge of combining inverter and charger is high because that would enable to remove a high power converter from the Bill of Material of the electric vehicle. In such case, we could also imagine having higher power AC fast charging solutions, if of course there is no impact or limited impact on the aging of the battery.

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