Deliverable D3.1 – Technical feasibility of en-route charging technical report

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UNPLUGGED: Wireless charging for Electric Vehicles

UNPLUGGED project aims to investigate how the use of inductive charging of Electric Vehicles (EV) in urban environments improves the convenience and sustainability of car-based mobility. In particular, it will be investigated how smart inductive charging infrastructure can facilitate full EV integration in the urban road systems while improving customer acceptance and perceived practicality. UNPLUGGED will achieve these goals by examining in detail the technical feasibility, practical issues, interoperability, user perception and socio-economic impacts of inductive charging. As one special variant, inductive en-route charging will be investigated thoroughly.

As part of the project, two smart inductive charging systems will be built, taking into consideration requirements from OEMs, energy utilities and end users. The systems will be innovative and will go beyond the current state of the art in terms of high power transfer, allowing for smart communication between the vehicle and the grid, as well as being in line with the latest inductive charging standards and considering interoperability. These innovative inductive charging systems designed and built as part of the project will then be tested and assessed in order to understand their potential impacts on urban mobility and the acceptance of e-mobility. Application in an en-route charging scenario in particular will be examined for different vehicle types, ranging from cars to buses.

It is anticipated that UNPLUGGED will provide clear evidence on and demonstrate whether the use of smart inductive charging infrastructure can overcome some of the perceived barriers for e-mobility, such as range and size of on-board energy storage, and practical difficulties associated with installing 2radetional charging post infrastructure.

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Abbreviations

AC	Alternating Current
BMS	Battery Management System
CBP	Circuit Braker Panel
CISPR	Comité International Spécial des Perturbations Radioélectriques
DC	Direct Current
ECU	Electronic Control Unit
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EV	Electric Vehicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
HMI	Human Machine Interface
ICNIRP	International Commission for Non Ionized Radiation
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPT	Inductive Power Transfer
ISO	International Organization for Standardization
LF	Low Frequency
LV	Low Voltage
PHEV	Plug-in Hybrid Electric Vehicle
PP	Prallel – Parallel
PS	Parallel – Serial
PWM	Pulse-Width Modulation
RE-EV	Range Extended Electric Vehicle
RFID	Radio Frequency Identification
SAE	Society of Automotive Engineers
SECC	Supply Equipment Communication Controller
SP	Serial – Parallel
SS	Serial – Serial
WPT	Wireless Power Transfer

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1 Executive Summary

Wireless charging can be a key-technology to promote customer acceptance of Electric Vehicles in urban environment because it can improve convenience and sustainability of EVs and reduce the so-called “range anxiety” of the customers.

To reach this goal it is necessary to analyze the impact wireless charging can have both on the vehicle-side and on the grid side, focusing particularly on the static en-route charging (Traffic light, Bus stop, Taxi stand, delivery truck).

This document focuses on the vehicle side aspects and on the related issues: storage systems, E/E architecture, on-board installation, driving impact, vehicle needs and synergies.

It starts with the analysis of the state of the art of the energy storage systems, from the standard battery for EVs and PHEV, to the alternative systems, such as supercapacitors or flywheels.
The major benefit of wireless charging is the possibility to reduce the energy stored on-board with the aim to reduce both the weight and the cost of the storage systems.
In order to quantify the energy reduction an analysis of standard and homologation driving cycle has been performed. But to enter in the real world, some data have been acquired from real driving cycle in urban environment and elaborated in order to furnish more suitable prediction.

This document analyzes the interaction between the vehicle and the infrastructure. A model has been developed to simulate vehicle behavior and analyze its impact on the road/infrastructure. Some simulations with different vehicle configurations have also been performed.

The analysis continues with some considerations on the installation on vehicle, both from the E/E architecture point of view (communication and electrical integration aspects) and mechanical integration (available space on standard vehicle).

As the focus of this document was static en-route charging, it was necessary to evaluate the impact of the wireless charging constraints on the driving needs; especially on positioning the vehicle to attain higher charging efficiencies.
An evaluation of the efforts for the driver to reach (or to near) the best positioning has been performed taking into account possible solutions that can be used as auxiliary systems.

In the end a general overview of the needs, opportunities and synergies with other developments for Unplugged project and in general for wireless charging technology is presented.

2 Analysis of feasible energy storage system

2.1 Standard storage system for EV: battery

The stored energy in the vehicle depends on the mission profile and on the “level of electrification”, from lower values for hybrid (mini, mild, full or plug-in) vehicles to higher values for fully battery powered vehicle.

Depending on the energy required to guarantee a minimum autonomy performance and avoid “range anxiety” from a customer perspective it is necessary to install an adequate battery pack.

Currently, the range of a traditional passenger car (segment B-C) is about 150-200 km, that corresponds to 20 kWh, considering an average energy consumption of approximately between 0,11 and 0,16 kWh/km.[1]

For light commercial vehicles a lower range could be acceptable for specific missions (for example urban goods delivery in traffic within limited range of less than 100 km can be considered sufficient). Furthermore, the adoption of modular battery packs can allow customer to choose the desired range; generally, for light commercial vehicle with a cargo compartment (up to total mass of 3,5 ton), energy installed must be at least 40 kWh.

The below image shows the Ragone plot which compares power and energy densities of different battery technologies and also indicate their general applications.

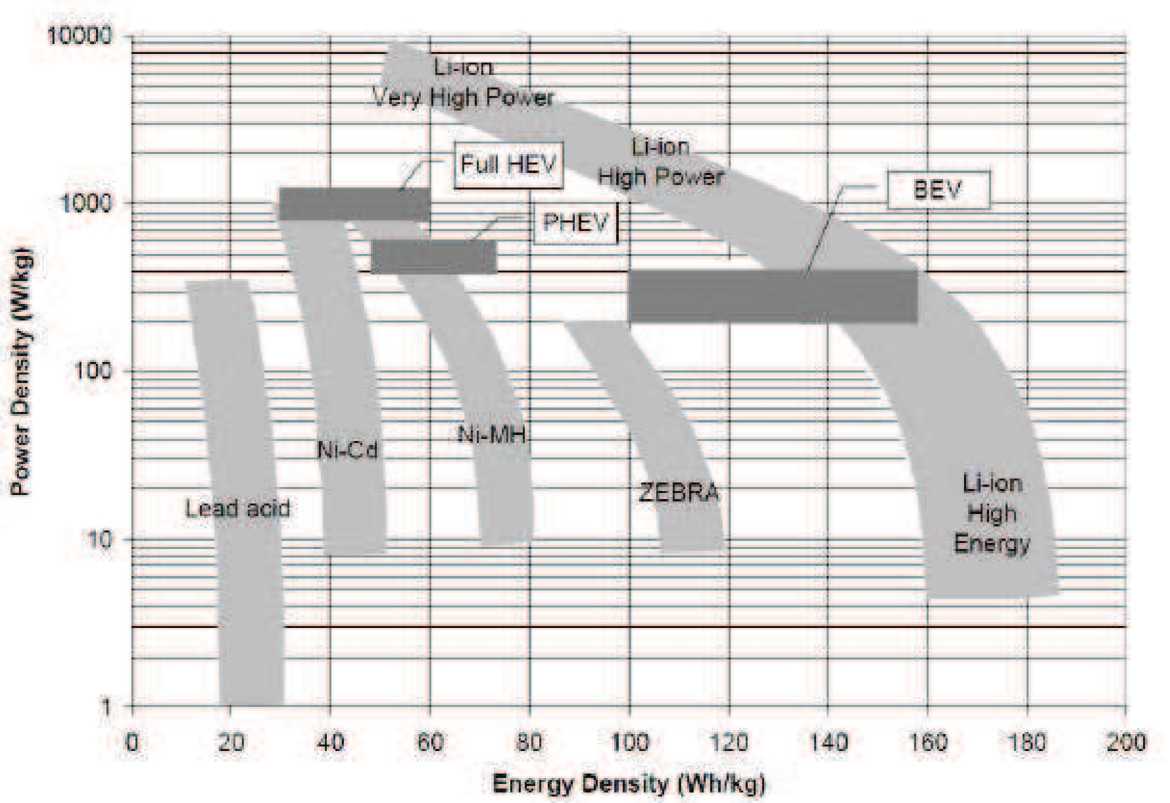


Figure 1: Ragone Plot - Energy and Power Density of Battery technologies

Situation has progressed quickly in the last years/months, with the Li-ion battery technologies showing huge growth also for hybrid applications, following the diffusion of plug-in hybrid vehicles performing pure electric mission (from few kilometres up to 50 km).[2]

Research and innovation on batteries inside automotive industry is moving in order to:

- Reduce the weight and cost for energy stored on vehicles

- Increase the range of vehicles to meet the current customer demands, derived by current habits of standard ICE vehicles.

In order to reach these purposes, two possible ways seems applicable in automotive industry and have been approached by OEMs and/or suppliers:

- Use of a so-called range extenders
- Charging every possible time and increasing the charging power, through infrastructure development for both conductive and wireless charging (at least in urban environment).

The first solution is already present in the market; some electric vehicles can be bought by customers in two versions, the pure electric and the range extender.

The adoption of an internal combustion engine as a range extender is quite simple for automotive industry, because it allows exploiting the decades of experience gained in petrol cars.

This architecture in the future could easily allow the adoption of different range extenders, such as fuel cell-systems.

The second solution is mostly related to the needs for a dedicated infrastructure development, both for conductive charging with fast charger sites and for inductive or wireless charging.

For the wireless charging, apart from the stationary case, the development of infrastructure for static en-route or for dynamic chargers in urban environment (for example through dedicated lanes), can be a key-element for the electric vehicle wide diffusion.

In the following images two schematics for a pure electric car and for a range-extenders vehicle are shown.

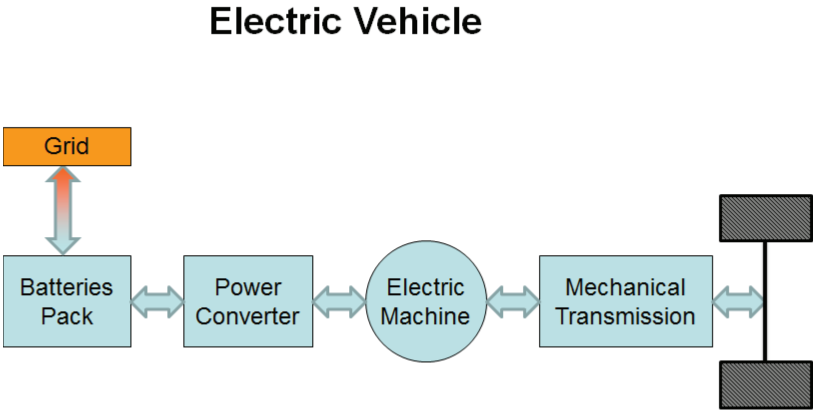


Figure 2: Electric Vehicle Architecture

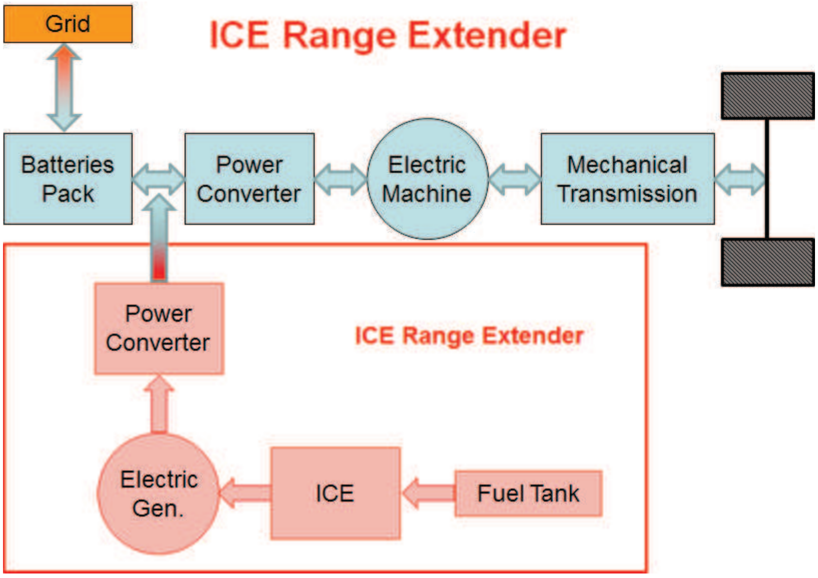


Figure 3: Electric Vehicle Architecture with ICE Range Extender

From the architecture schematics, it is evident that the adoption of a range extender system gives the opportunity to charge the vehicle from the grid without any constraints, allowing it to be charged both through conductive and inductive systems, depending on the choices or on the vehicle mission.

2.1.1 Lithium Batteries analysis

Analyzing the Ragone plot, it is clear that for full electric vehicle the Lithium batteries are the best technology both for power and energy densities.

The Lithium based technologies' evolution is continuous, moved by e-mobility increasing interest and obviously by the consumer electronics for low power systems.

First lithium batteries existed since the Seventies, starting with portable applications, because of their little needs for maintenance.

Current lithium batteries can be stored up to 10 years; indeed, the warranty of OEMs and suppliers for batteries on hybrid or electric vehicle is around this time duration.

Lithium batteries can be divided in three classes: solid state batteries, batteries with a solid cathode and batteries with soluble cathodes.

On the market, the two most common primary lithium batteries are the lithium disulphide ($LiFeS_2$) and lithium manganese dioxide ($LiMnO_2$); both are solid cathode type and are present in consumer electronic products.

During the last few years, battery with a cathode with different electrode materials have been developed and tested. The aim was to have a system that can satisfy both high and low loads.

Currently, the most common kind of lithium batteries is the lithium ion type; it negative electrode consists of a carbon based material (usually graphite), or another type of alloy that permits intercalation.

Main advantages of lithium batteries in comparison with other battery technologies are the high energy and power density, low self-discharge and long recharge lifetimes (up to 1000 cycles full discharge).

Some limitations can arise from the issues related to low and high temperatures (above 55°C), high costs and safety aspects.

Today there are many different chemical variants of the lithium base batteries, based on the cathode material. Common cathodes are made from cobalt dioxide ($LiCoO_2$), also with nickel ($LiNi_{1-x}Co_xO_2$, more stable and less expensive); some other kinds of cathodes are based on manganese oxide spinel ($LiMn_2O_4$) that are in general cheaper but have a low energy density.

In recent years, lithium ion batteries with cathodes made from lithium iron phosphate ($LiFePO_4$) have been marketed on a large scale, because of their higher safety levels and low cost. The benefits of $LiFePO_4$ have been achieved at the expense of their energy density and voltage.

R&D in this sector has the following targets:

- A transition to cheaper and less toxic electrode materials (cathodes, including phosphates, silicates, etc.)
- A transition to materials that have higher, reversible lithium reception (greater absorption of lithium atoms leads to higher battery capacity)
- The development of materials that can withstand rapid charges (from 0 to 90% SOC in ten minutes)
- Battery for the automotive industry and stationary applications (power supplies and energy supplies)
- Increased cell size in the form of stored energy capacity
- Battery systems with high voltage levels (including electrolytes that can withstand higher electrode potential without degrading or reacting with the environment)
- Battery system with enhanced safety (compared to current battery types).

Currently, the research is driven mainly by the automotive industry, which needs high-performance with long calendar and charge lifetimes, high power both in charge and in discharge phases with a target cost affordable by customers.

New research and development is focused on titanate and anodes composed of tin, carbon and silicon that have entered the commercial battery market. The main advantage of titanate is in its highly stable structure and its lack of increase in volume during battery charging. Silicon is especially interesting in the way that it permits very large quantities of lithium to be stored in the anode structure. Moreover, the material is neither expensive nor toxic.

Regarding the development on the cathode side, there are many options: materials under tests include metal phosphates, layered metal oxides, and silicates. The metal phosphates are being promoted thanks to their chemical stability, leading to increased safety compared to traditional cobalt based cathode materials. Magnesium and manganese phosphates, as well as iron silicate, are also all relatively cheap and non-toxic materials. The layered metal oxide structures are expected to offer rapid lithium mobility, thereby permitting high charge and discharge currents, but the material is still relatively expensive and associated with safety problems.

2.1.2 Battery definitions and constraints for automotive applications

In the figure below, a comparison between Lithium-based battery technologies is shown.

Choice is of course conditioned by the application, but the automotive industrial constraints are very tight.

Mixing all these features and finding the right compromise should bring out the best choice for a specific application.

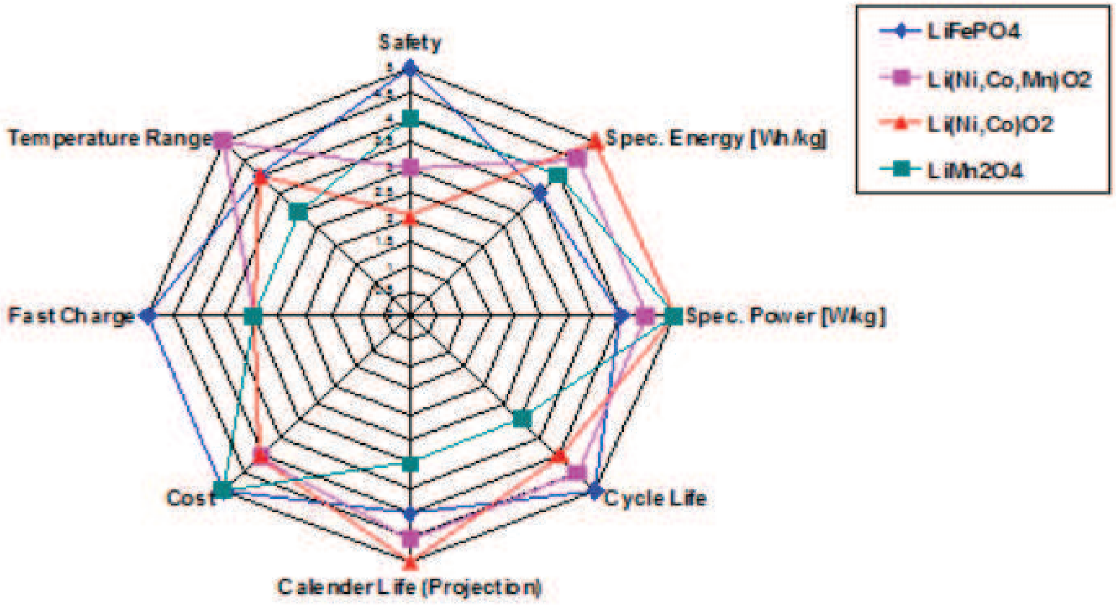


Figure 4: Lithium-based battery technologies comparison

Indeed, for in-vehicle applications, all the elements taken into account in the diagram are very important:

- Safety: battery system behavior with its related safety mechanism must be guaranteed in normal use, in case of accident, during maintenance, etc.

- Specific Energy [Wh/kg]: higher value is better for the integrating them inside the vehicle, for increasing range and for better mass distribution with a meaningful impact on drivability of the vehicle.
- Specific Power [W/kg]: as for the specific energy, it is important to guarantee vehicle performance (also for hybrid application) with limited weight.
- Cycle Life: it is defined as the number of cycles a battery can perform before reaching its end of life without letting some features go outside acceptable limits. (Features mainly depend on type, usage, producer of battery, etc.).
- Calendar Life: it is the elapsed time before a battery becomes unusable whether it is in active use or inactive
- Cost: probably represents the major issue with the current electric vehicle diffusion.
- Fast Charge: it presents the opportunity to the electric vehicles to reach standard ICE vehicle's fast refulling capability. (in general it is considered a fast charge a process that takes less than one hour charging at 1.0C rate)
- Temperature Range: higher temperature takes to faster chemical reactions and higher SOC reduction.

In general, for batteries application it is important to highlight some constraints and clear some definitions.

Battery types for traction application are distinguished in two main categories:

- Energy Batteries: batteries for which the numerical ratio between maximum allowed electric power output (power in W) and electric energy output (energy in Wh) at a 1C discharge rate at Room Temperature is typically lower than 10. These storage devices typically are installed on Electric Vehicle.
- Power Batteries: batteries for which the ratio between maximum allowed electric power output and electric energy output at a 1C discharge rate at RT for a battery pack or system is typically equal or higher than 10. These batteries typically are used for high instantaneous power boost on Hybrid Vehicles.

Batteries have a finite life due to occurrence of chemical and physical changes that are generally irreversible and affect the electrical performance of each battery cell.

The End-of-life is defined on the basis of some specific features going outside acceptance limits (features mainly depend on type, usage, producer of battery, etc.).

There are two indicators to define End of Life:

- Nominal Capacity: generally used for Energy Batteries
- Internal Resistance: generally used both for Energy and Power Batteries

According to these indicators, a battery reaches its End of Life when:

- Its nominal capacity goes under a value that is usually fixed at 80% or 70% of its initial rated capacity, or alternatively when
- Its internal resistance increases by an amount usually 1, 2 times its initial value.

For a specific application like wireless charging, in particular for an application such as the "en-route" charging, with frequent charging processes and without time-controlled phases, it is important to highlight the factors that can influence batteries ageing:

- Cycling: desired chemical reactions are usually accompanied by unwanted ones which consume some of the active chemicals or impede their reactions
- Depth of discharge: the ratio between the maximum discharged capacity during the cycle and battery nominal capacity: higher percentage discharge leads to lower expected number of cycles
- Temperature: higher temperature leads to faster chemical reactions and higher SOC reduction
- Overvoltage: the overcoming of maximum allowable voltage reduces batteries life. The overvoltage can be due to overcharging conditions

- Type of cycle: cycles having an high energy throughput affects more the battery life and high power cycles stress the batteries often operating nearby the voltage limits
- Undercharge: if SOC goes under a low threshold, large crystals tend to form and number of dendrites increases. these crystal modifications can lead to higher auto-discharge and even lead to internal short-circuits during recharging

Therefore, the battery management becomes very important and the following factors must be taken into account:

- Temperature ranges:
  - Range of full performance use: 10÷40 °C
  - Range of derated performance use: -10÷10 °C or 40÷60 °C
  - Range of shelf life: -20÷70 °C
- SOC management: taking into account that the depth of discharge has a strong influence on battery life, the SOC swing has to be managed.
- Near the upper and lower SOC thresholds higher peak currents have to be avoided.
- Charge/Discharge management: Lithium batteries have no problems related to charge interruption (absence of “memory effect”), but require a balancing system, in order to avoid thermal runaway effects that can occur in misuse conditions like overcharging/overdischarging.
- In a battery pack consisting of many cells connected in series/parallel, the weakest cells are the bottleneck of whole chain, affecting the vehicle performance. Therefore, the balancing system has the function of leveling the charge of each cell.

Furthermore, in fast charging, for the evaluation of the wireless charging, especially for the “en-route” charging, it is important to highlight that battery charging generally consists of two phases, one defined as the “constant current” (that allows maximum power transfer) and the other “constant voltage” (with a current and power reduction and keeping the voltage at the maximum cells limit).

For this reason, even if the charger system can reach high power transfer and is defined “fast”, the maximum current value is allowed only at SOC values lower than a threshold (generally 80%, but it depends on the batteries).

In the figure below a typical battery charging process is shown.

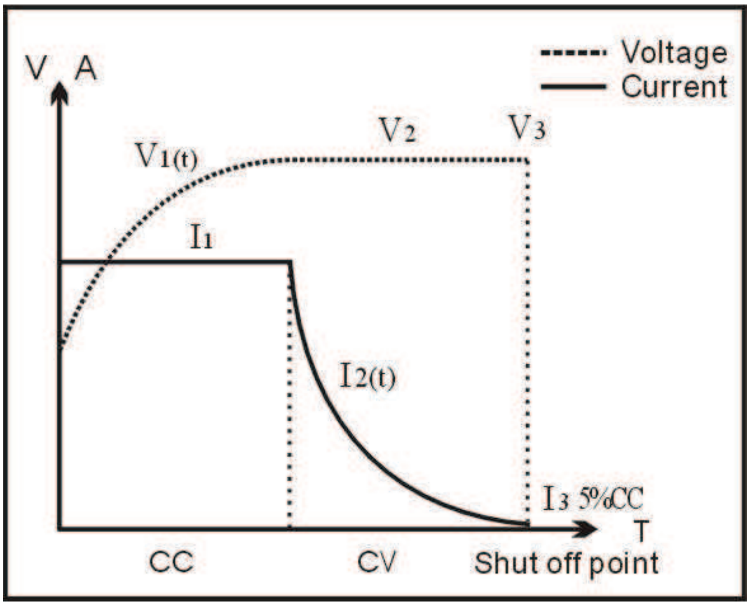


Figure 5: Battery charging process - Constant Current and Constant Voltage

According to these factors, in the next section an analysis of driving cycle has been performed to highlight the possible impact a wireless charging infrastructure can have on a vehicle mission.

2.2 Driving Cycle Analysis

On an electric vehicle the battery pack is a key element for its two main aspects: the weight and the cost, both of which are related to the total energy stored and the chosen technology.

Reducing the stored energy can bring benefits on these two aspects.

Wireless charging technology, with the “en-route” charging, can enable this reduction.

In order to better understand the reduction in stored energy some analysis on driving cycle can be performed.[3]

2.2.1 Standard Driving Cycle

In the hypothesis of installing wireless charging coils underneath the roads at traffic lights or bus stops or at the taxi stands, the range of a BEV can be increased and in parallel the battery can be reduced.

At the moment, different standard driving cycles are used by OEMs in different countries which OEMs have to refer to while stating their vehicles performance in terms of range and emission:

- European standard ECE-EUDC combined urban test cycle
- U.S. standard FTP 72 (Federal Test Procedure) cycle also called Urban Dynamometer Driving Schedule (UDDS)

Features of these urban test cycles under consideration are shown in the figure below.

It is assumed that the time a vehicle spends idling during a journey in a test cycle is the time for which the vehicle has stopped at traffic signals.

Cycle	Distance (km)	Duration (s)	Idle duration (s)	% Idle
ECE-EUDC	11,0	1180	261	22,1
UDDS	12,0	1369	234	17,1

Figure 6: Comparison between standard driving cycles for Europe and United States

2.2.1.1.1 ECE-EUDC or NEDC cycle

The New European Driving Cycle is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars (excluding light trucks and commercial vehicles). It is also referred to as MVEG cycle (Motor Vehicle Emissions Group).

The NEDC is supposed to represent the typical usage of a car in Europe. It consists of four repeated ECE-15 Urban Driving Cycles (UDC) and an Extra-Urban driving cycle (EUDC).

The speed profile is shown in the following figure.

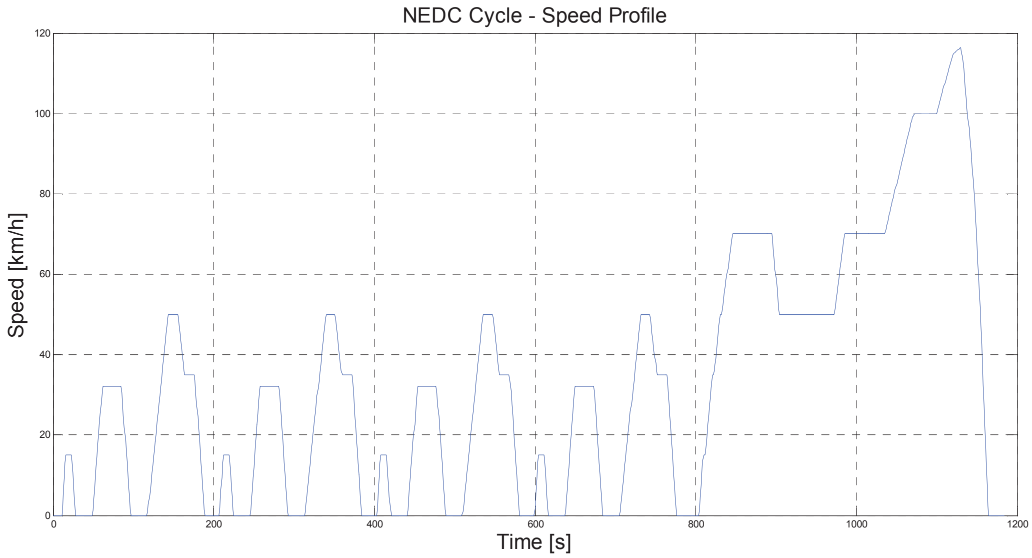


Figure 7: NEDC speed profile

In the ECE-EUDC, 22,1% of the total cycle is spent in idling conditions.

2.2.1.1.2 **UDDS cycle**

UDDS is the Urban Dynamometer Driving Schedule, and it refers to an United States Environmental Protection Agency mandated dynamometer test on fuel economy. It represents city driving conditions which are used for light duty vehicle testing.

The UDDS cycle is shown in table below.

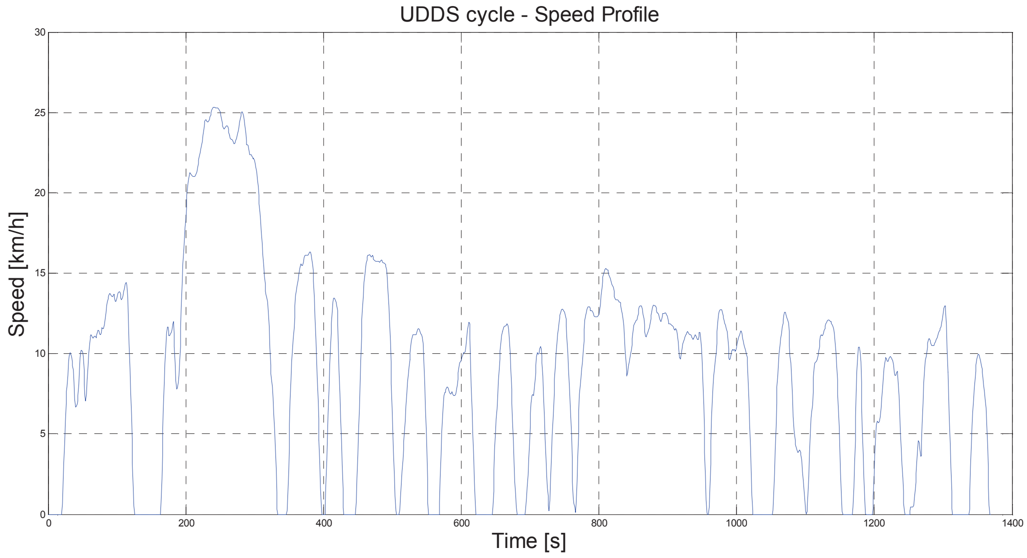


Figure 8: UDDS speed profile

In the UDSS cycle, 17,1% of the total cycle is spent in idling conditions.

2.2.1.2 Vehicle Simulations on NEDC Driving Cycle

In order to evaluate the impact of wireless charging on the range of a vehicle some simulations have been performed on the NEDC cycle.

For different kind of vehicles, a small car and a van, an evaluation of the requested force to move the vehicle and follow the speed profile has been performed, using data coming from a simple vehicle simulator.

From the force profile, power and energy requested have been calculated and reported to power and energy flowing from/to a battery, taking into account an electric powertrain supplied by a battery pack.

Some hypotheses have been made for the simulation, regarding the efficiency of the powertrain (both for traction and regenerative braking phases), the battery capacity and efficiency.

Efficiency Electric machine as Motor	Efficiency Electric machine as Generator	Efficiency Transmission	Efficiency Battery Out process	Efficiency Battery In process
0,8	0,7	0,8	0,9	0,8

Table 1: Hypotheses on efficiency of electric powertrain

A calculation of the possible power and energy of the wireless charging en-route system has been performed in the idle phases of the cycle.

For the simulation a standard car and a van have been considered.

Vehicle	Total mass	Frontal area	Coefficient of rolling resistance	Coefficient of drag	Wheel Radius
Small Car	1200	2,2	0,01	0,335	0,26
Van	1900	4	0,13	0,350	0,288

Table 2: Vehicle data for simulations

Different simulations have been performed: a basic value of the amount of energy necessary to follow the cycle has been calculated. Starting from this value, different simulations with three different wireless charging systems (for different maximum powers have been performed:

- 3,7 kW
- 20 kW
- 50 kW.

The overall efficiency of the wireless charging system has been set to 80%.

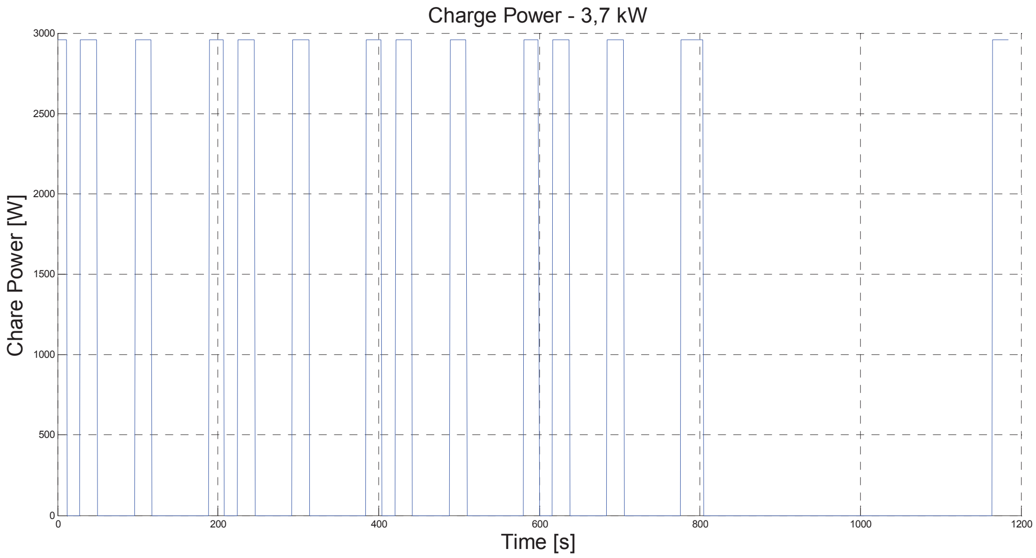


Figure 9: Charge Power on NEDC idle phases - 3,7 kW

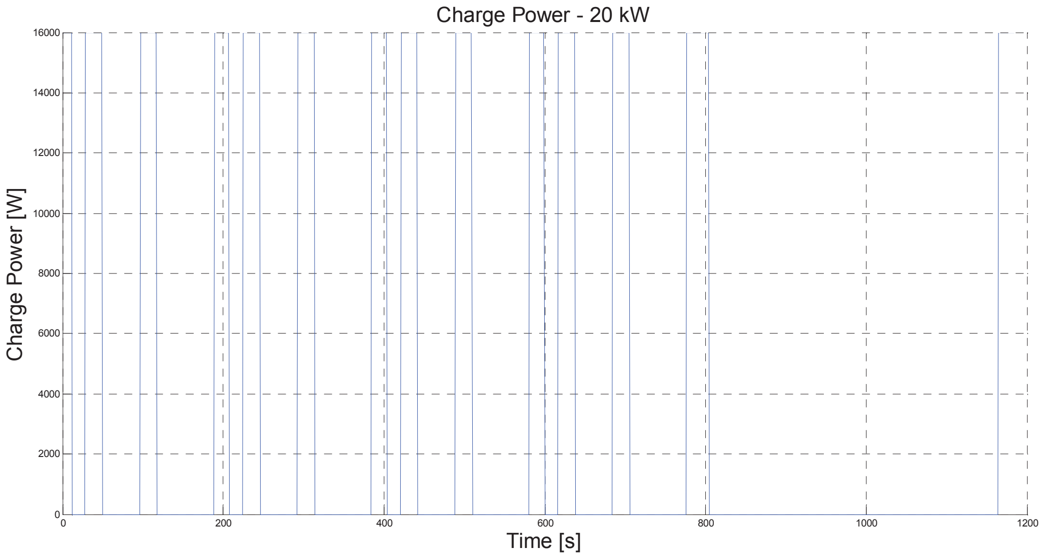


Figure 10: Charge Power on NEDC idle phases - 20 kW

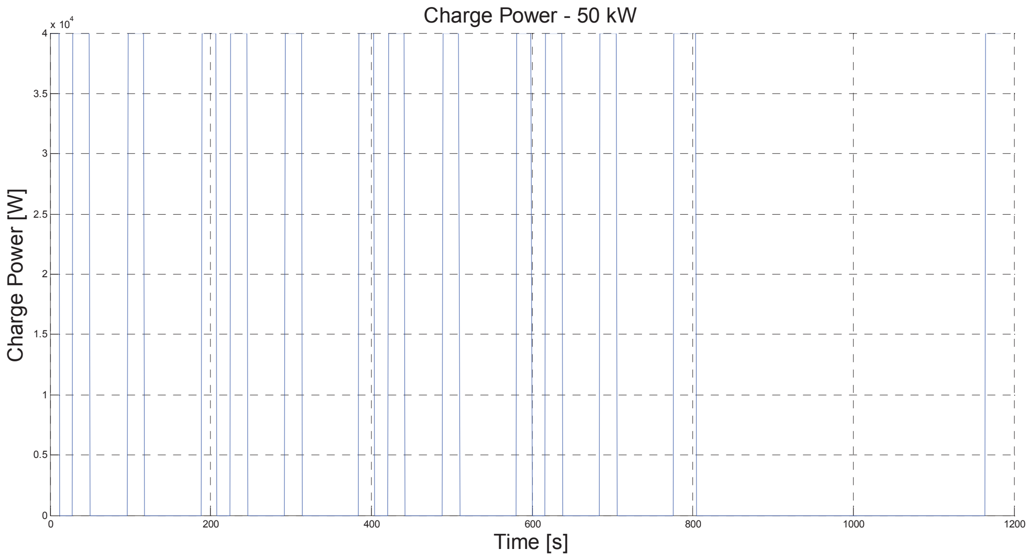


Figure 11: Charge Power on NEDC idle phases - 50 kW

The results of the simulation are reported in the next figures.

For the Small Car two charging profiles have been simulated ,one starting from 80% SOC with a 3,7 kW wireless charging systems and one starting from 60% SOC with a 20 kW wireless charging system.

The battery capacity for the Small Car is assumed to be 20 kWh.

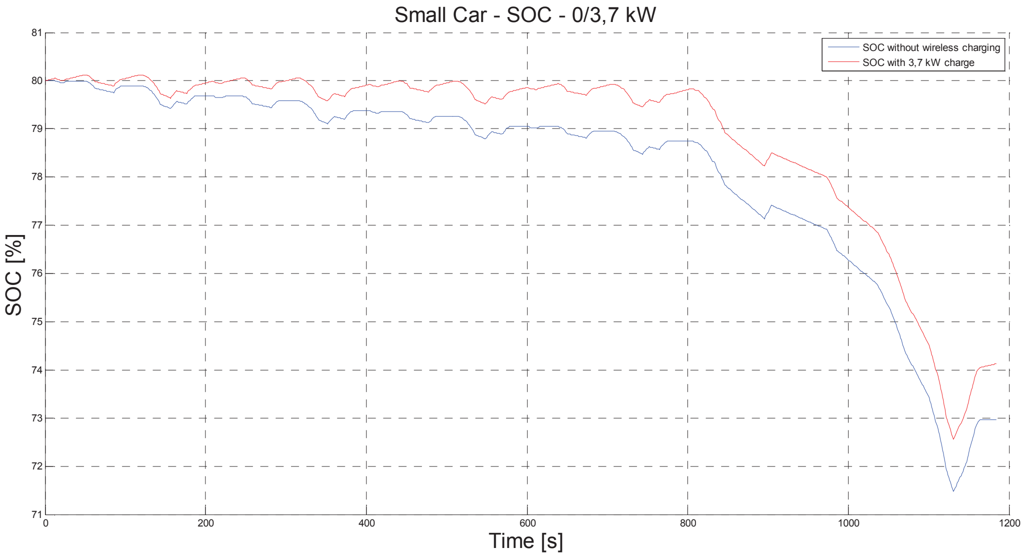


Figure 12: SOC on NEDC idle phases for a Small Car - 3,7 kW

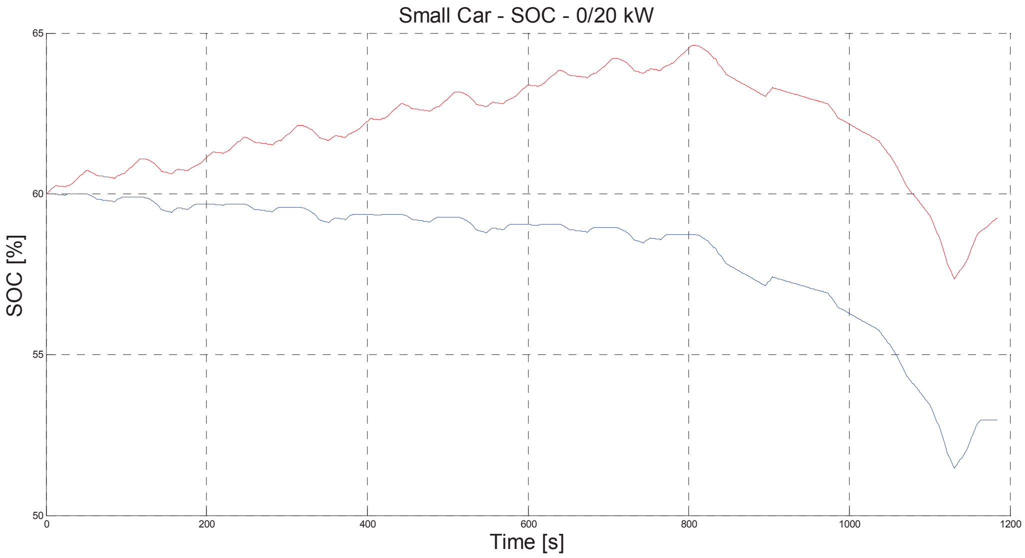


Figure 13: SOC on NEDC idle phases for a Small Car- 20 kW

In the following table the data elaboration related to a small car are reported: table contains the energy required (EnergyCycleRequired) to perform the cycle, the overall variation of energy inside the battery (DeltaEnergyCycle), the overall percentage SOC variation (DeltaSOCCycle), the energy variation due to the charging system (DeltaEnergyCh), the percentage SOC variation due to charging sys(tem DeltaSocCh) and the percentage energy reduction through the cycle due to the wireless charging system (DeltaEnergyReduction)**..**

EnergyCycleRequired [kWh]	**DeltaEnergyCycle [kWh]**	**DeltaSOCCycle [%]**	**DeltaEnergyCh [kWh]**	**DeltaSocCh [%]**	**DeltaEnergyReduction [%]**
1,4079	1,4079	-7,04	0	0,00	0,0
1,4079	1,1752	-5,88	0,2327	1,16	16,5
1,4079	0,1501	-0,75	1,2578	6,29	89,3

Table 3: Small Car - Comparison between charging systems on NEDC cycle for a Small Car

For the Van, three charging profiles have been simulated ,one starting from 80% SOC with a 3,7 kW wireless charging systems, the second starting from 80% SOC with a 20 kW wireless charging system and the third starting from 60% SOC with a 50 kW wireless charging system.

The battery capacity for the Van is assumed to be 40 kWh.

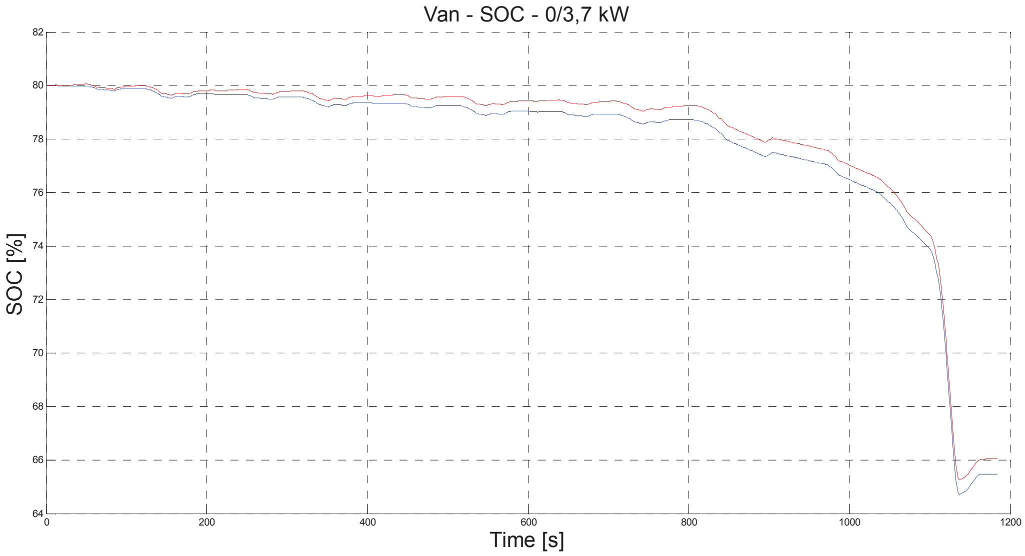


Figure 14: SOC on NEDC idle phases for a Van - 3,7 kW

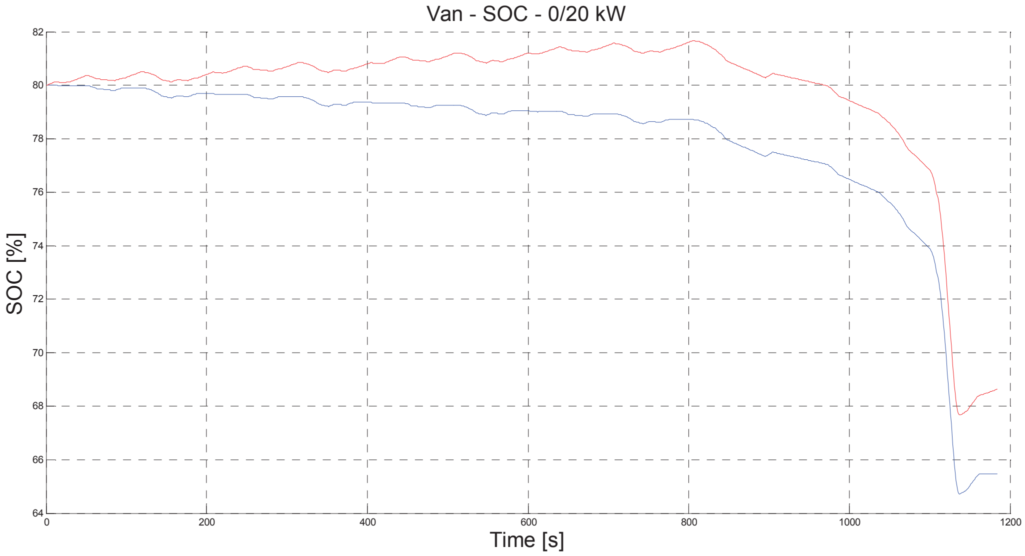


Figure 15: SOC on NEDC idle phases for a Van - 20 kW

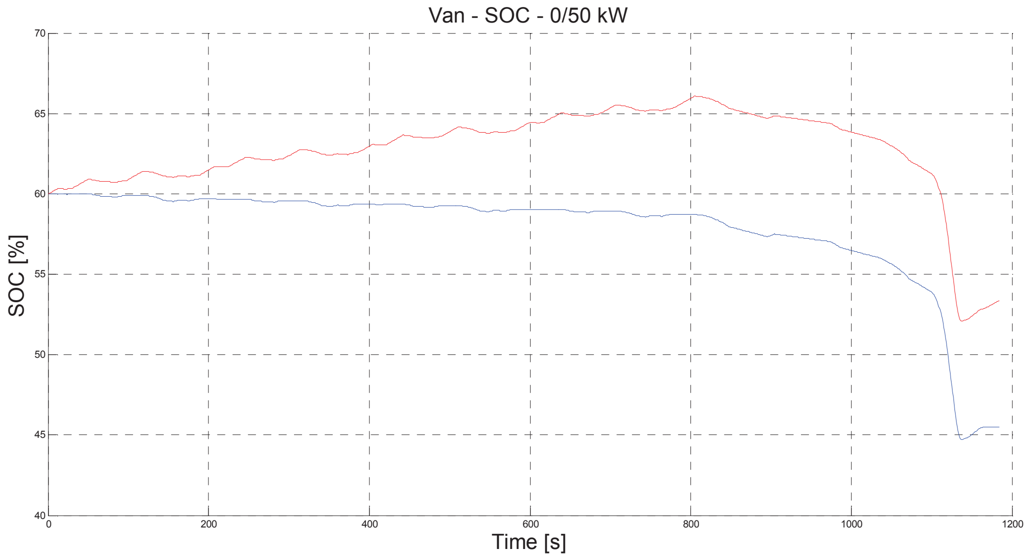


Figure 16: SOC on NEDC idle phases for a Van - 50 kW

As for the small car, the data are summarized in the following table.

EnergyCycleRequired [kWh]	DeltaEnergyCycle [kWh]	DeltaSOCCycle [%]	DeltaEnergyCh [kWh]	DeltaSocCh [%]	DeltaEnergyReduction [%]
5,8071	5,8071	-14,52	0	0,00	0,0
5,8071	5,5744	-13,94	0,2327	0,58	4,0
5,8071	4,5493	-11,37	1,2578	3,14	21,7
5,8071	2,6626	-6,66	3,1444	7,86	54,1

Table 4: Small Car - Comparison between charging systems on NEDC cycle for a Van

From the analysis of the results, some conclusions can be derived.

For a Small Car, the 3.7 kW can be useful in an urban environment; indeed the SOC profile is approximately stable in the ECE part of the NEDC cycle.

The 20 kW seems to be oversized with respect to the urban cycle, but useful to put energy in the battery for the second part of the NEDC cycle, the EUDC.

For larger vehicles, in particular considering specific missions, such as goods delivery and additional load for the vehicle, high power systems seems to be necessary in order to complete a mission longer than a standard driving cycle.

The 3,7 kW system does not seem to be sufficient enough to restored the used energy; both the 20 kW and 50 kW systems cover the EUDC part of the cycle (the first, urban part).

From a theoretical point of view, for a Small Car equipped with a 20 kW system, about 89% of energy necessary for the NEDC cycle could be restored through wireless charging, allowing a huge reduction in battery size.

For a Van equipped with a 50 kW system, about 54% of energy necessary for the cycle could be restored through wireless charging.

From this analysis, an hypothetical reduction of the battery size could reach up to 50% of the current capacity, with big benefits in terms of weight and cost.

SOC strategies can be added on real vehicles with the following objectives:

- To reduce battery cycling to prevent battery life reduction, for example by enable wireless charging only below a SOC threshold (e.g., 40%)
- To avoid the charging above a SOC threshold in order to prevent overcharge on the battery, taking into account that at high SOC the power must be reduce to prevent overvoltage in the battery.

The simulations performed give the opportunity to estimate the overall energy flow from/to battery and to evaluate mission vehicle calculations.

These simulations use only average values for the charging; an improvement can be the introduction of a dynamic profile for charging power and efficiency of the entire wireless charging system.

2.2.1.2.1 Other driving cycle: WLTP

A new driving cycle is under development in order to harmonize the ranges and emissions evaluation for different counties, it is the WLTP.

The Worldwide harmonized Light vehicles Test Procedures (WLTP) defines a global harmonized standard for determining the levels of pollutants and CO2 emissions, fuel or energy consumption, and electric range from light-duty vehicles (passenger cars and light commercial vans).

The aim of WLTP is to reduce differences between consumption acquired through the homologation cycles and real use of vehicle. Proposal cycle is “more nervous” compared to NEDC and percentage of idle time is lower than the current European homologation cycle.

The duration of idle time for the WLTP is about 195s for a total of 1800s, which represent about the 10% of the total duration.

According to this cycle, the opportunities for wireless charging is reduced.

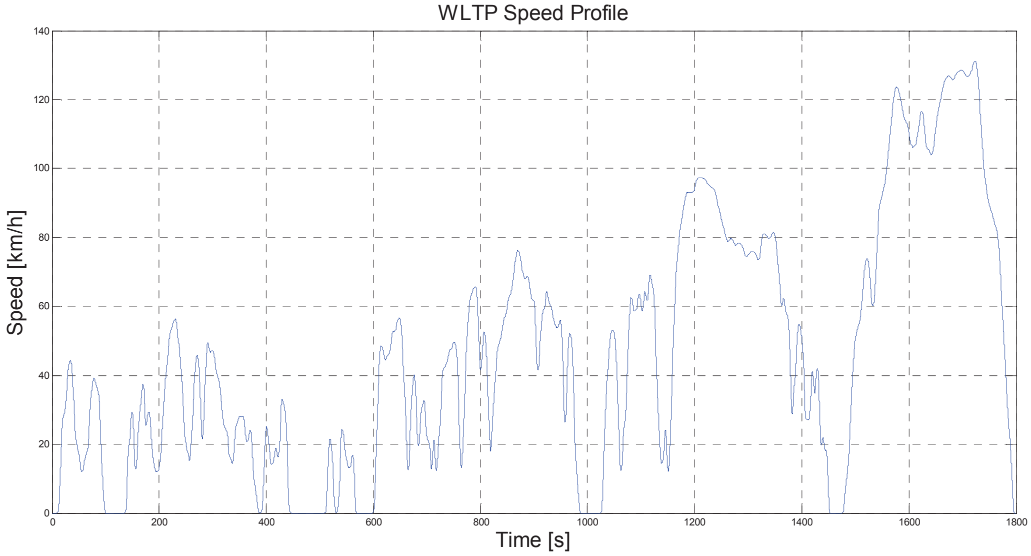


Figure 17: WLTC Speed Profile

2.2.2 Urban Driving Cycle (Real Test)

Further conclusions can be made through data elaboration for real test on Urban Driving Cycle.

From some real tests performed in urban environment, in Turin city, it is possible to make a comparison between data simulations coming from the NEDC cycle and real data acquired.

The tests performed show that the idle conditions in real environment can reach up to a range between 32% (total duration about 1800s) to 36% (total duration about 1500s) of the vehicle mission.

So the energy that can be delivered through battery from wireless charging system can vary depending on the system power, from a lower value of 0,5 kWh for a 3,7 kW systems up to 6 kWh for a 50kW systems.

These values are higher than the idle conditions percentage coming from standard driving cycles; of consequence, wireless charging could give additional benefits in real environments.

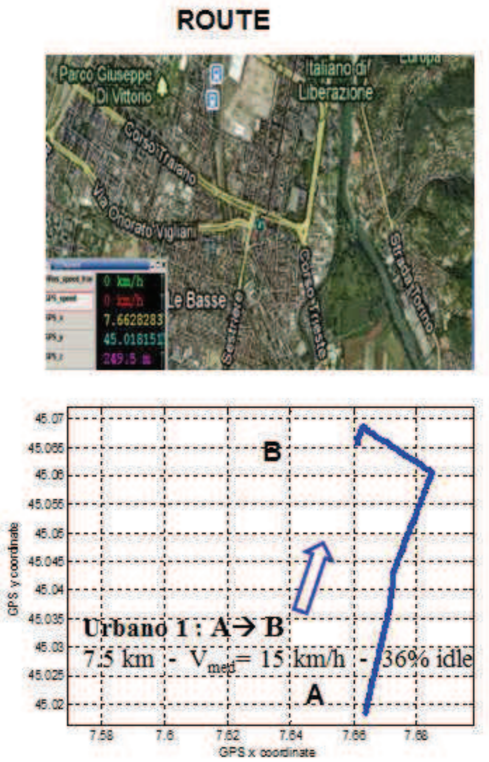


Figure 18: Urban environment - Test A

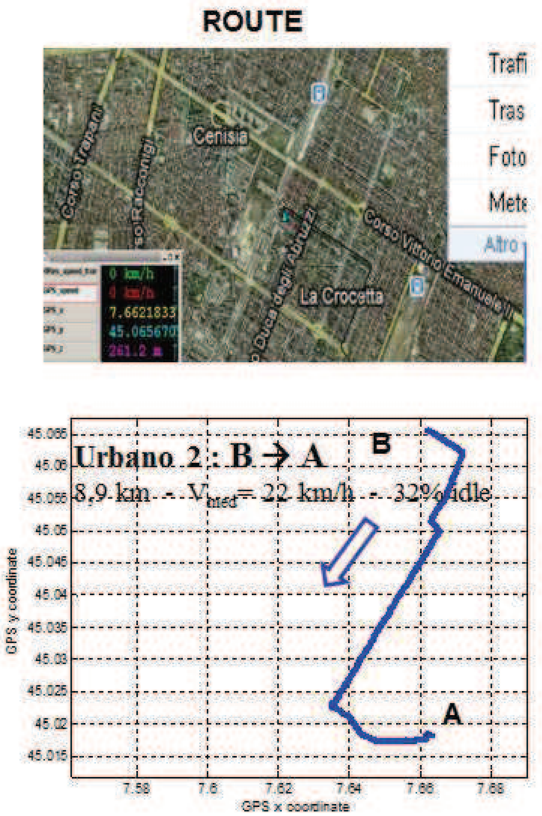


Figure 19: Urban environment - Test B

2.3 Alternative Energy Storage System

In order to overcome some battery limitations, alternative energy storage systems are continuously under analysis; the objective being not only to find a valid substitution to battery technologies, but also to find combined solutions for maximizing reliability and increasing power responses both in charging and discharging phases.

In the following paragraphs an overview of ultracapacitors and flywheels technologies is given.

2.3.1 Ultracapacitors

2.3.1.1 Ultracapacitors technology overview

2.3.1.1.1 Conventional capacitors

Considering conventional electrolytic capacitors, electric charge storage capability comes from the available storage area on the flat metallic conductive material of the electrode plates. High values of capacitance can be obtained by winding great lengths of plate's material, (increase in the total surface area). Charge separation between layers is achieved by dielectric material (plastic, paper, ceramic films, etc.). Thinner dielectric allows increasing capacitance, also because higher area can be created within a specified volume. The technological limit is therefore the limitation to the thickness of the dielectric, which indirectly defines the surface area achievable.

Conventional capacitors are able to provide relatively high power density values per unit mass or volume (W/kg), but on the other hand these devices have very low energy density (Wh/kg) when compared to other energy storing systems. Consequently, conventional capacitors can provide a high power pulse, but for a very short period of time.

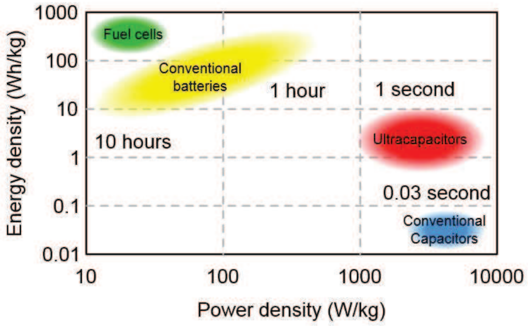


Figure 20: Ragone plot for electrical storage systems

2.3.1.1.2 Ultracapacitors technology

The physical principle behind Ultracapacitors (also known as supercapacitors) is the same as for the conventional capacitors.

The breakthrough manufacturing characteristics is that electrode materials can have high surface area, greater than using flat plates or films. The electrodes are wound together with an electrolyte, and the charge separation distance is then determined by the size of the elements (ions) in the electrolyte, which are attracted to the charged electrode. Ultracapacitors can thus achieve capacitances several orders of magnitude larger than conventional capacitors (hundreds of Farads), with greater energy densities while still maintaining the characteristic high power density of conventional capacitors (because of similarly low ESR (Equivalent Series Resistance) values).

Ultracapacitors have several advantages over electrochemical batteries and fuel cells like higher power density, shorter charging times, and longer cycle life and shelf life. Ultracapacitors are based on electrostatic reactions (not electrochemical reactions), so charge and discharge cycles are totally reversible, and can be repeated hundreds of thousand times, making them ideal for applications with high cycling requirements.

This performance improvement allows ultracapacitors to occupy a region between conventional capacitors and batteries. The greater capacitances are in fact not sufficient to match the energy densities of mid to high-end batteries and fuel cells. Thus, much of the investigation focuses on achieving energy densities more comparable to those of batteries.

Ultracapacitors are a good option for a variety of applications: power pulse compensation systems, regenerative energy solutions and energy storing systems for vehicles, applications where a quick charging is needed or energy backup systems. As a summary the Table 5 describes the main characteristics of ultracapacitors in comparison with batteries and conventional capacitors.

	Electrochemical batteries	Ultracapacitors	Conventional capacitors
Charge time	1 – 5 hours	0.3 – 60 s	1 ms
Discharge time	0.3 – 3 hours	0.3 – 60 s	1 ms
Energy density (Wh/kg)	20 – 100	< 10	< 0.1
Power density (W/kg)	1,000	> 10,000	> 10,000
Cycle life (# cycles)	1,000	> 500,000	> 500,000
Efficiency	0.70 – 0.85	0.9 – 0.98	0.95

Table 5: Performance comparison of electrical and electrochemical energy storage technologies

2.3.1.1.3 Classification and Construction Details

Ultracapacitors can be classified, based upon trends on reaction systems and materials used, in three families: Electrolytic Double Layer Capacitors (EDLC's), Pseudo capacitors, and the Hybrid family.

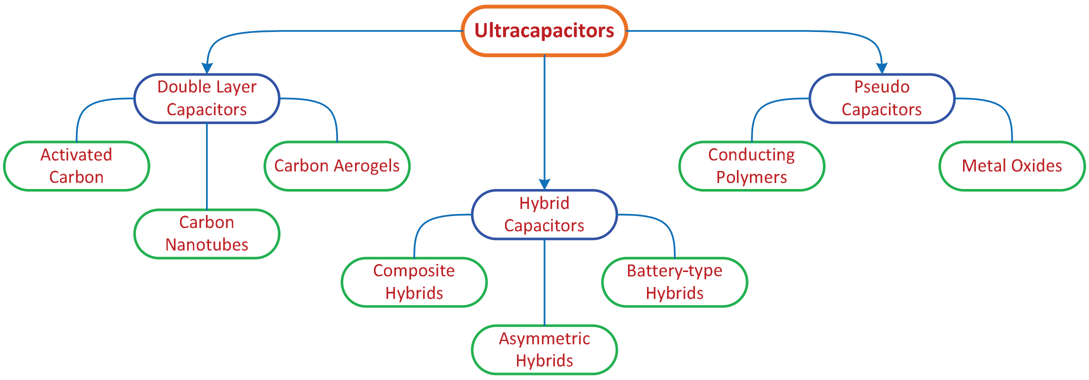


Figure 21: Classification of ultracapacitors according to manufacturing technology

Further details on EDLC, Pseudo capacitors and Hybrid capacitor are described in

Annex 1.

2.3.1.2 Construction

The assembly of the ultracapacitors can vary from product to product. This is due in part to the geometry of the ultracapacitor packaging. For products having a prismatic or square packaging arrangement, the internal construction is based upon a stacking assembly arrangement with internal collector paddles extruding from each electrode stack. These current collector paddles are then welded to the terminals to enable a current path outside the capacitor.

For products with round or cylindrical packaging, the electrodes are wound into a jellyroll configuration. The electrodes have foil extensions that are then welded to the terminals to enable a current path outside the capacitor.

The final product commercialization can be done in several shapes. In order to achieve higher working voltages or capacities, some suppliers provide module solutions (banks of capacitors) similar to electrochemical batteries, with several rows of ultracapacitor cells connected. Prismatic construction is very useful in this case, since provides compactness and easily assembly solution. These modules can include balancing systems, cooling systems and CAN bus connectors for automotive applications.

2.3.1.3 Electrical Specifications and Parameters

The characterization of an ultracapacitor consists a lots of electrical and performance parameters; in this paragraph, a selection of the most relevant ones are provided.

- Capacity (C): Individual ultracapacitor cells can reach very high capacitive values, already commercially available, around 5000 F, thanks to an increase of surface area of electrodes and decrease (in the order of nanometers, almost vanishing) of dielectric thickness.
- Voltage (V): Ultracapacitor voltage differs from conventional capacitors. Since ultracapacitor is lacking of conventional dielectric layer between electrodes, this interface can only withstand small potential values, from 1 to 2.7 V. The type of electrolyte used has a great influence on the final rated voltage of the cell. To achieve higher working voltage, several individual cells are connected in series like high voltage electrochemical batteries. Overcharging do not affect ultracapacitors, once ultracapacitor is charged, it can be kept under rated voltage charge and working temperature range practically without any effect on the cell life. On the other hand, cells exposed to overvoltage can be damaged depending on time and temperature during exposition.
- Internal Resistance (ESR): Relative low resistance value of ultracapacitors compared to electrochemical batteries is the main reason why ultracapacitor can achieve high power densities.
- Maximum Continuous Current (Icmax): As current causes self-heating, working current has influence on the ultracapacitor cycle life. This parameter represents continuous or RMS current that can be fed in the ultracapacitor without increasing the device’s temperature beyond the supported range.
- Charge and Discharge: Ultracapacitors shows linear relationship with voltage during charge and discharge, but the linear relationship with voltage can be changed to constant voltage by simply connecting DC-DC converter.
- Temperature: Temperature is the main factor affecting cycle life of ultracapacitors, similar to conventional capacitors. The extended working temperature range of ultracapacitors makes them a very attractive solution as energy storage systems in extreme temperature environment. Common working temperature ranges of ultracapacitors are from -40ºC to 65 ºC, extremes where a rechargeable electrochemical battery would not perform, unless a serious reduction in capacity is accepted. There are some new developments of ultracapacitors ready to go to the market able to withstand up to 85 ºC, specific for automotive applications.
- Cycle Life: Even the cycle life of a ultracapacitor is almost infinite compared to a battery, in fact an ultracapacitor has a specified endurance and an end of life. Ultracapacitor life is mainly affected by a combination of operating voltage and operating temperature. The ultracapacitor does not experience a true end of life rather the performance continually degrades over the life of the use of the product. End of life will be when the ultracapacitor performance no longer maintains the application requirements

2.3.2 Applications of ultracapacitor technology

Ultracapacitors applications can cover different energy solution demands in several industries: automotive, energy, consumer applications and so forth. Our attention, among the several possible applications of these devices, is focused on the transportation and automotive industry applications.

Besides of typical electronic applications in the automotive industry, a big increase in the use of ultracapacitors is expected in automotive industry due to an eruption of hybrid vehicles and EV's, and introduction of regenerative systems and idle systems, because of the need of industry to reduce car consumption due to restrictive policies against CO_2 emission.

During the design of EV's or hybrid vehicles, the battery unit is dimensioned considering the vehicle autonomy but also to cover power requirements (acceleration requirements), resulting in an oversize of the system, that results in an increase in weight, volume and cost of battery pack. Moreover, the electrical currents involved with regenerative breaking in the hybrid/electric powertrain, or cold cranking in starters for standard/S&S powertrains, are sometimes huge, and not always manageable by lead-acid or lithium-based batteries, unless batteries oversizing is accepted.

The limitations related to batteries could be overcome by combining the use of batteries with ultracapacitors as power buffers. Ultracapacitor would operate during the peak power periods, by supporting battery power supply or storing the energy from a regenerative system. Thus ultracapacitor compensates the loss of power of a reduced battery and helps to avoid overheating of batteries during these periods, increasing at the same time the battery life and a reduction of the battery thermal management systems, with cost and weight savings.

Examples of potential applications of ultracapacitors in automotive industry are:

- Warm cranking for fuel efficient Stop-Start systems;
- Cold cranking support to extend battery life;
- Regenerative energy capture during braking/coasting;
- Distributed power systems to reduce wiring loom size/weight/cost;
- Drive-train support in Hybrid Electric and Electric Vehicles, including Fuel Cell vehicles).

In some cases, where power and energy requests are compatible with the installed capacity of the supercapacitors, the battery could altogether be removed from the vehicle, simplifying the architecture of the system and aiding in other aspects like thermal management and lifecycle/reliability, that are more delicate in power batteries.

2.3.3 Flywheels

2.3.3.1 Energy storage in flywheels

A flywheel stores energy in a rotating mass. Depending on inertia and speed of the rotating mass, a given amount of kinetic energy is stored as rotational energy. The flywheel is placed inside a vacuum containment to eliminate friction-loss from the air and suspended by bearings for a stable operation. Kinetic energy is transferred in and out of the flywheel with an electrical machine that can function either as motor or generator. When acting as motor, electric energy supplied to stator windings is converted to torque and applied to the rotor, causing it to gain kinetic energy through higher speeds. In generator mode kinetic energy stored in the rotor applies a torque, which is converted to electric energy. The picture below shows the basic layout of a flywheel energy storage system. Apart from the flywheel, additional power electronics is required to control the electric machine (power input and output, speed, frequency, etc.).

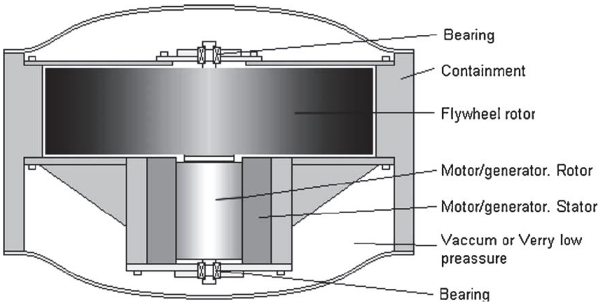


Figure 22: Basic layout of a flywheel energy storage system

The speed limit of a flywheel is set by the stress developed within the wheel due to inertial loads, called tensile strength. Lighter materials develop lower inertial loads at a given speed; therefore composite materials, with low density and high tensile strength, are excellent for storing kinetic energy.

In most designs a rotational speed drop of 50% is allowed, thus the available energy is 75% of the stored energy, in other words the depth of discharge is 75%. Overall the flywheel geometry and speed determines the energy storage capability, whilst the motor/generator and power electronics determines the power capabilities.

In the market, there are systems already available with which also include the mechanical interface (left). Some manufacturers offer assemblies including in the same enclosure more than one flywheel energy storage unit, for instance there are four-flywheels configurations (right).

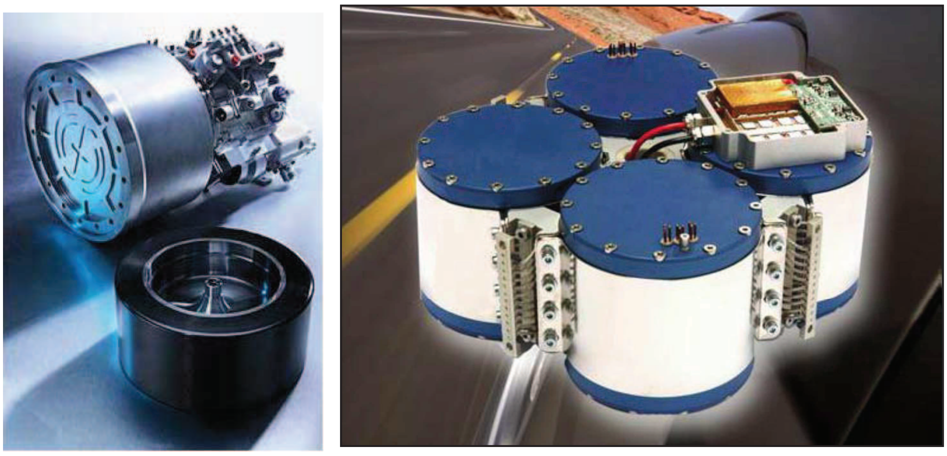


Figure 23: Examples of flywheel systems on the market

2.3.3.2 **General manufacturing and material aspects**

From kinetic energy formulation, it can be understood that an increase in angular velocity has more effect on the energy stored than the mass of the flywheel itself. In portable applications, moreover, mass must be kept as low as possible while maximizing the energy stored in the flywheel. For this reason maximum velocity has been gradually increased through time.

When the angular velocity of the disk is increased the disk undergoes much higher centripetal force, and this is where the material science breakthroughs have allowed flywheels to spin at speeds surpassing 60k rpm. With such high velocity, older metal flywheels would fly apart, whereas new carbon fiber and epoxy flywheels are able to withstand the higher forces seen in modern flywheels. The potential of carbon fiber and epoxy flywheels have been recognized by many manufactures and is being utilized by nearly all of them, quickly becoming an industry standard. Looking at the overall flywheel system, although the flywheel itself is made of the carbon fiber epoxy composite, most of the encasing and shafts are still made of steel or aluminum.

Table 6 shows a summary of the potential for different materials in terms of energy stored and possible velocity achievable in flywheel configuration. The best results are obtained with composite materials, reaching hundreds of Wh/kg.

	Flywheel material	Density [g/cm3]	Tensile strength [MPa]	Maximum specific kinetic energy for 1 kg mass ring [Wh/kg]	Maximum peripheral velocity or tip speed [m/s]
All metal thin ring	Aluminum 7075 T651	2.80	469	23.3	409
	Titanium Ti-6A1-4V, STA	4.43	965	30.3	467
	Steel 4340, QT	7.70	1500	27.1	441
All composite thin rim	E-glass / epoxy	2.15	1679	108	884
	S-glass / epoxy	2.07	2235	150	1038
	AS4 carbon / epoxy	1.61	2111	182	1145
	IM7 carbon / epoxy	1.61	2589	224	1270
	IM9 carbon / epoxy	1.62	2993	257	1360

Table 6: Overview of technology trade-offs in flywheels and related maximum performance

Further technical considerations on flywheel are described in

Annex 1.

2.3.4 Focus on potential applications of flywheels in automotive industry

Research and application of flywheels influences different fields of interest: automotive and aerospace industries, small electrical energy generation buffering, harmonics compensation in electrical distribution, UPS systems, and more.

In automotive scope, small scale peak power buffer is the target application for flywheels. Small-scale flywheel energy storage systems have relatively low specific energy figures, but have high specific power, constrained only by the electrical machine and the power converter interface, making this technology more suited for buffer storage applications. Development of alternative dual power source electric vehicle systems that combine a flywheel peak power buffer with a battery energy source has been undertaken. The uses of a flywheel as peak power buffer in an electric vehicle can significantly reduce the peak currents drawn from the ordinary storing supply e.g. battery. Elimination of the peak currents will prolong the battery life, improving lifetime and reliability of the whole system. The main issue about this integration is that the flywheel is really useful only if the system really requires huge electric current pulses that are out of the boundaries for batteries, otherwise, with peaks comparable with the limits of the batteries, the use of flywheels, similarly to the use of ultracapacitors, has no practical sense.

2.3.4.1 Applications of flywheel energy storage systems to hybrid vehicles

Almost every vehicle with a manual transmission is already fitted with a flywheel to smooth the flow of power from the engine and to provide a small storage of energy to help prevent stalling on launch.

High-speed flywheel energy storage is something different because of the higher amount of energy involved, since it is essentially a substitute or an assistant to a battery system.

There are two main ways of transferring power from the vehicle to the flywheel and back again. One system uses a continuously variable transmission (CVT), while the other uses electric motors and generators to transfer the power to and back out of the flywheel. Each of these systems has advantages and disadvantages in different ways.

The CVT system (Figure 24) has the advantage of less energy loss, as the power does not go under any phase changes. This being said, the CVT system is a heavier system, which limits the overall benefit of the design.

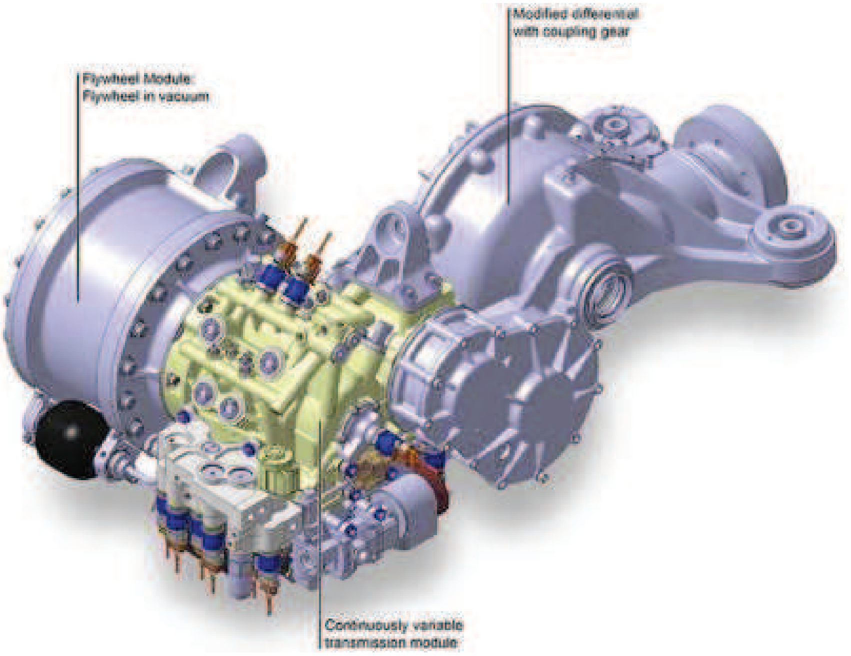


Figure 24: Example of CVT configuration of flywheel-hybrid powertrain (Volvo)

Figure 25 shows the flow of energy involved with boost and recuperation phases, underlining the fact that there is no conversion to other forms of energy, just different steps of conversion of mechanical energy, from flywheel to road wheels, by means of the CVT gear.

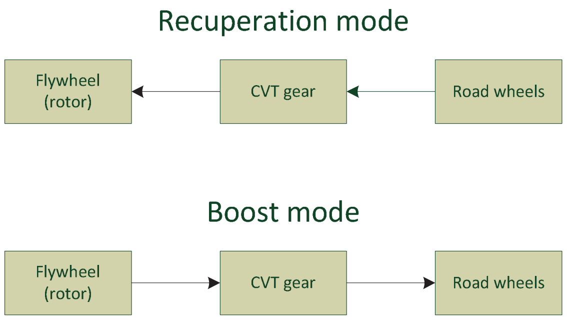


Figure 25: Block diagram representation of energy/power flow in CVT-flywheel hybrid vehicles

The electrical flywheel (Figure 26) allows for many more car designs, as the placement of the flywheel does not have to be in line with the transmission and can be placed anywhere in the car. The electrical design also has drawbacks, since it needs extra motors/generators to transfer power between electric and mechanical phases, which means significant energy loss.

Figure 26: Example of electrical configuration of flywheel-hybrid powertrain (Williams f1)

Figure 27 shows the flow of energy in the two directions for the electrical configuration of flywheel systems, in which the transportation of energy is driven by electric energy; the road wheels are equipped with electric motors, that in the regenerative braking phase spill kinetic energy, that is sent to the flywheel electric machine in order to accelerate the flywheel rotor. In the reverse path, flywheel is slowed down by its electric machine, which provides the spilled energy to the road wheel motors in order to help the vehicle in acceleration, in addition to the traditional engine. There are two different energy types involved, so several transformations or conversions, implying intrinsic lower efficiency of this configuration.

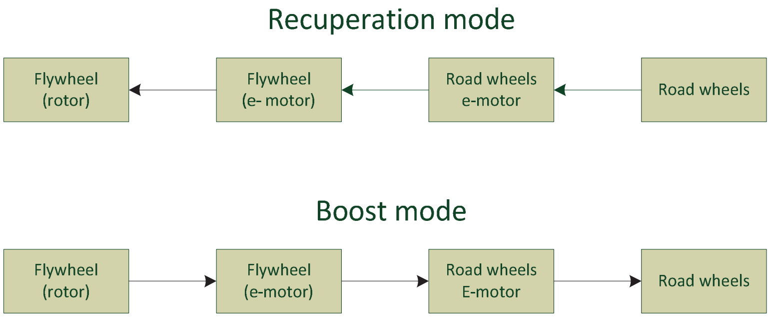


Figure 27: Block diagram representation of energy/power flow in electric-flywheel hybrid vehicles with in-wheel traction motors

With either of the previously described flywheel systems, an advantage over other hybrid systems is that the amount of power held within the system is easily tracked. This is not the case with other common hybrid systems such as batteries, where the stored energy is more of a rough estimate. While Lithium-ion batteries do have a higher energy density they are unable to charge and discharge at the rates seen by flywheels and ultra-capacitors. With the power which can be quickly drawn from the high speed flywheel it is possible for a relatively small engine to make a car feel as if it were a much more powerful car.

In comparison with other battery storage technologies, flywheel KERS offers:

- Cycle durability - 90% efficiency of flywheel (including power electronics) in both directions during typical duty cycle.
- Extensive operating temperature range.
- Steady voltage and power level, which is independent of load, temperature and state of charge.
- High efficiency at whole working speed range.
- No chemistry involved, thus no environmental pollution and great recycling capability.

2.3.5 Comparison of storage technologies

In the end, a brief general comparison of the main properties of the different storage technologies can be provided. Figure 28 represents the cycling capability of the different technologies, showing the better results for flywheel solution, with chemical batteries offer less potential in these terms. Figure 29 shows the operating temperature range, and also in this case the better performance is up to flywheels, with ultracapacitors slightly better than chemical batteries. Figure 30 is about the voltage stability related to the different solutions, and also in this case flywheels seem to be more reliable (obviously, this is the case only for electrical configurations, since in CVT configurations it makes no sense considering voltages); for its nature, ultracapacitor is the worst candidate in voltage stability criteria, since it linearly discharges with low energy contents.

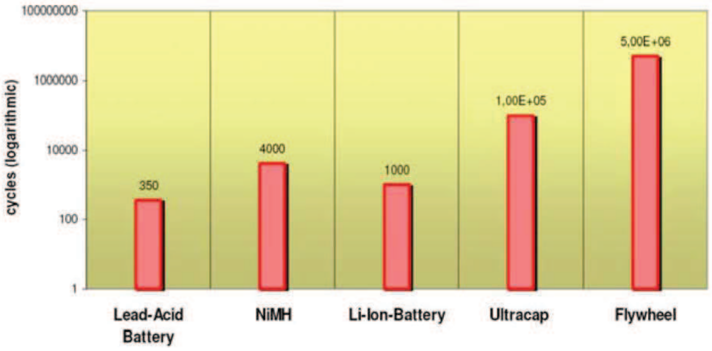


Figure 28: cycle durability comparison chart

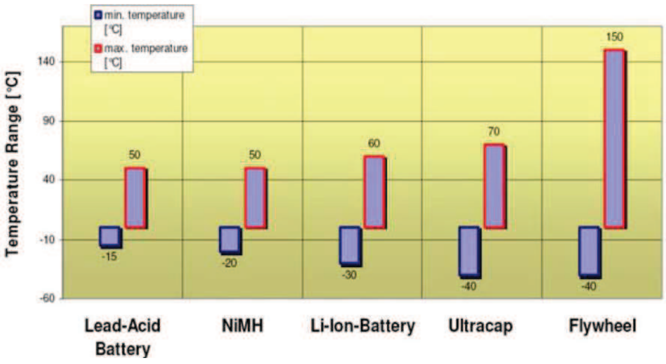


Figure 29: operating temperature range comparison chart

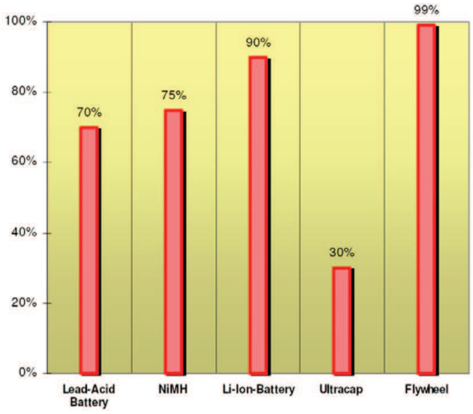


Figure 30: voltage stability comparison chart

In the end, a recapitulatory Ragone plot is presented in Figure 31, including not only the electrochemical storage systems, but also their mechanical counterpart, the flywheels. It can be seen that from the energy content point of view batteries and chemical storage systems on the whole are the best options, while in terms of power ultracapacitors deliver the best figures. Flywheels are located in an intermediate region, so on paper it seems that flywheels can be the correct tradeoff between the opposite trends of energy and power densities. The main concerns are about the efficiency of the system, since the conversion and transformation of energy from one form to another implies significant loss of energy, that is not always affordable in hybrid systems. Moreover, the use of flywheels and supercapacitors is suitable where the application requires peak power consumption and therefore a power buffer is justified, otherwise there is a consistent risk that the storage device not be so effective in the energy management.

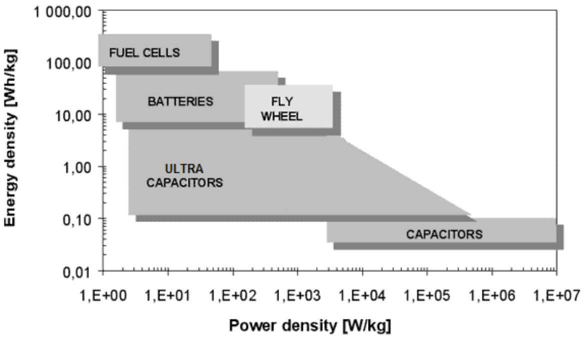


Figure 31: Ragone plot of energy storage devices including also flywheels

3 Analysis of the impact of the pick up coils on the vehicle dynamics at low speed

3.1 Pick-up localization on the vehicle

On a passenger car, the localization of the battery pack is fundamental for the weight considerations.

In the following pictures, three possible coil installations are presented, showing the space frame in front, central and rear part of the vehicle.

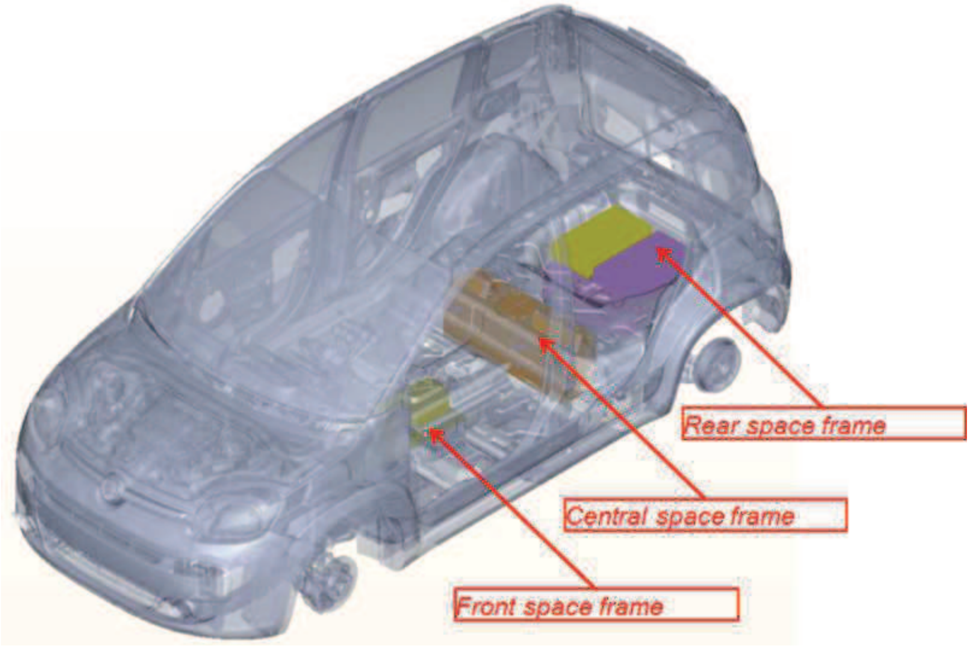


Figure 32: Passenger Citycar space frame analysis

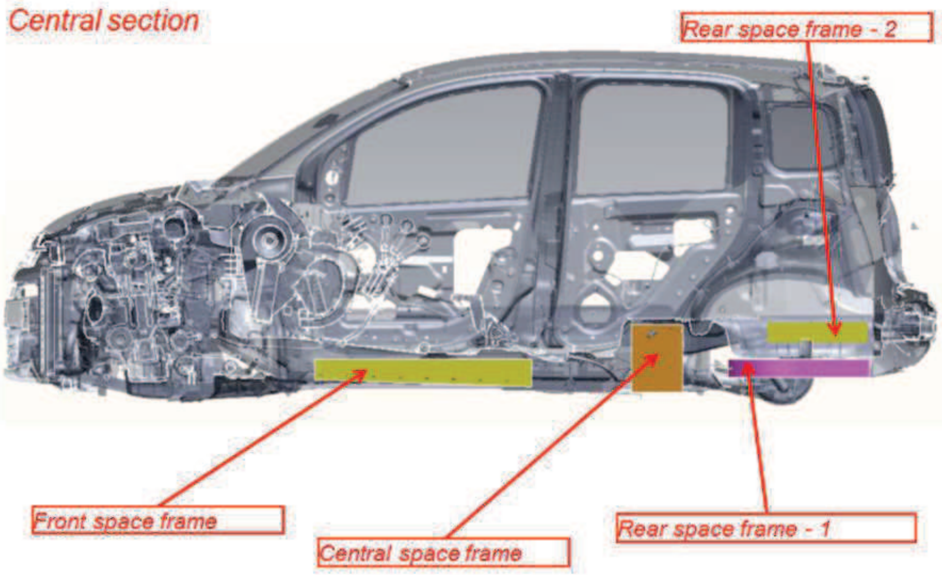


Figure 33: Passenger Citycar space frame analysis

According to a standard vehicle chassis, not specifically designed for battery pack and wireless charging system installation, analysis has been concentrated to define some possible space frames that could be useful both for battery integration (or part of the battery pack) and for the secondary coil of a wireless system.

Both the front and the central space frames could be used for the battery pack installation, in order to keep the vehicle barycentre as low as possible with advantages for vehicle dynamic and driveability.

If different positions are defined for the battery installation, these space frames could be used for the integration of the secondary coil.

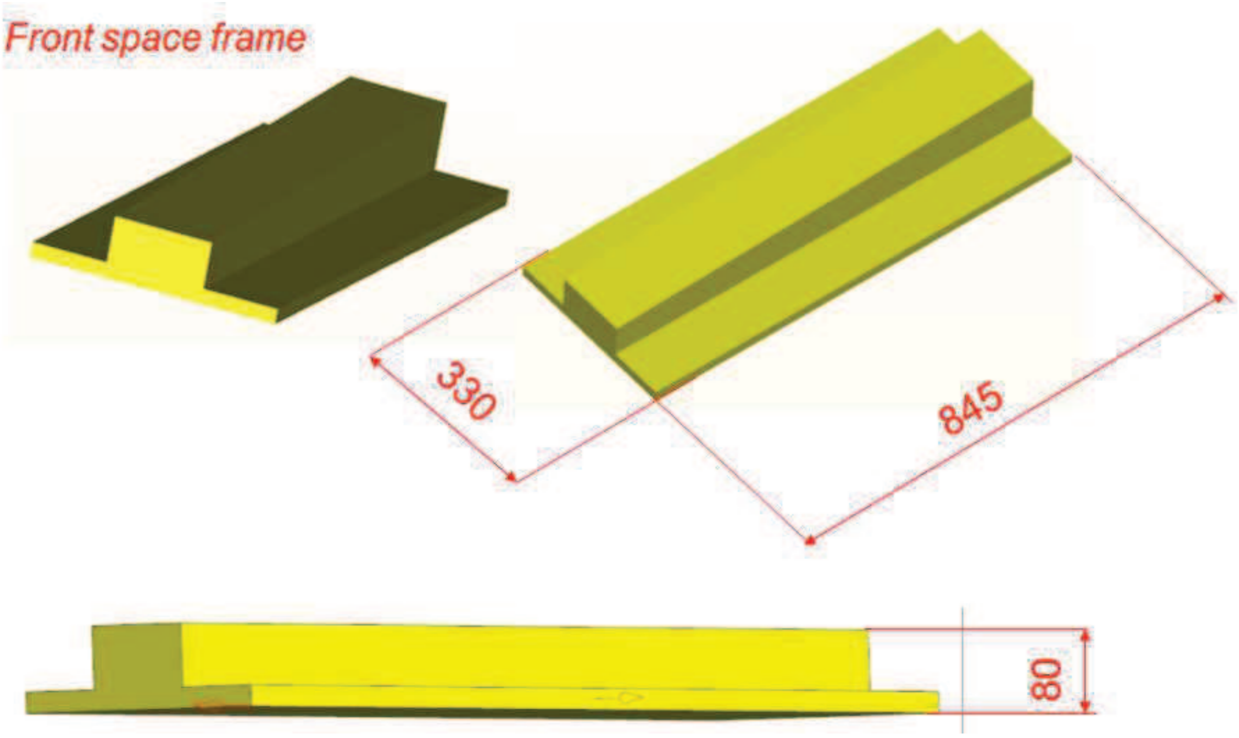


Figure 34: Front space frame dimensions

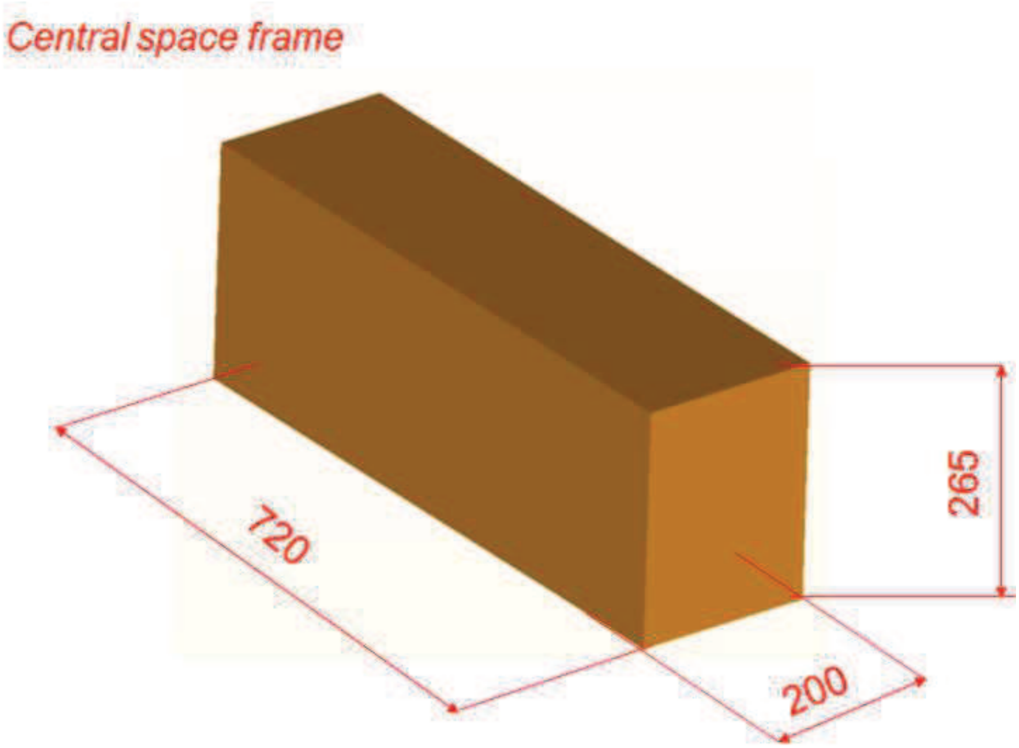


Figure 35: Central space frame dimensions

Interesting is the analysis of the rear part of the vehicle, where the space normally occupied by the spare wheel can be used both for the integration of the secondary coil and for the installation of the power electronics.

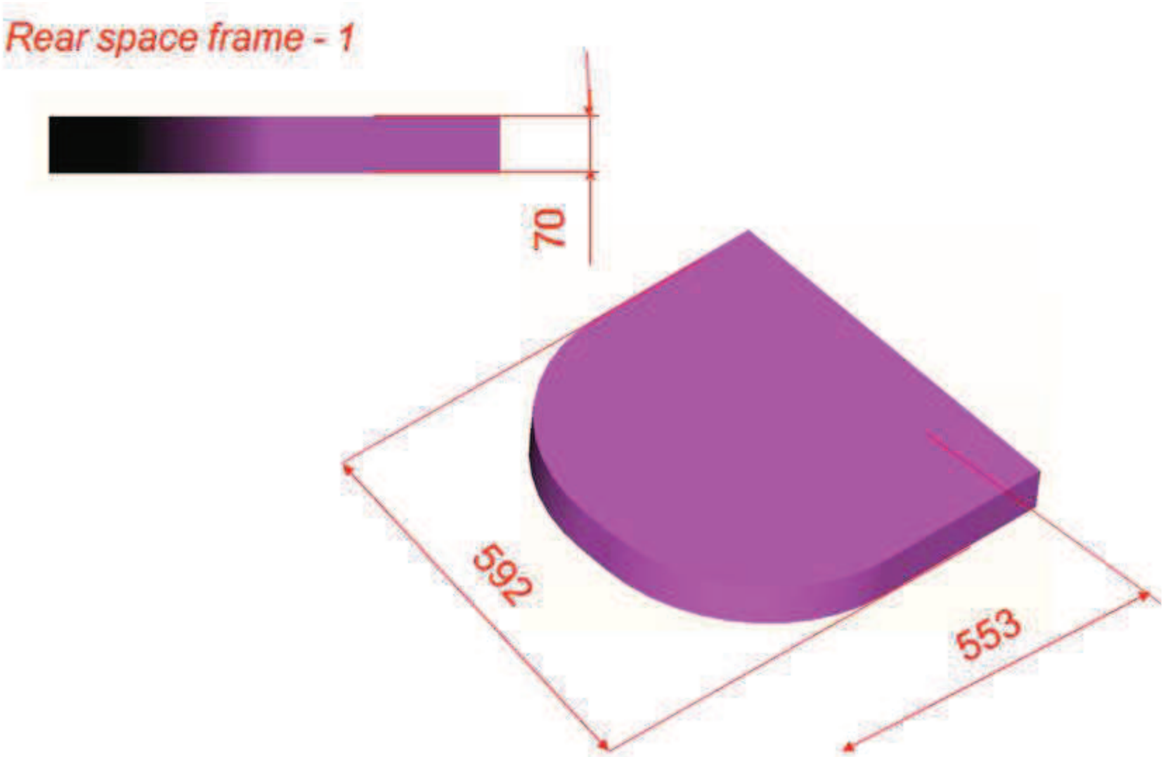


Figure 36: Rear space frame - 1 dimensions

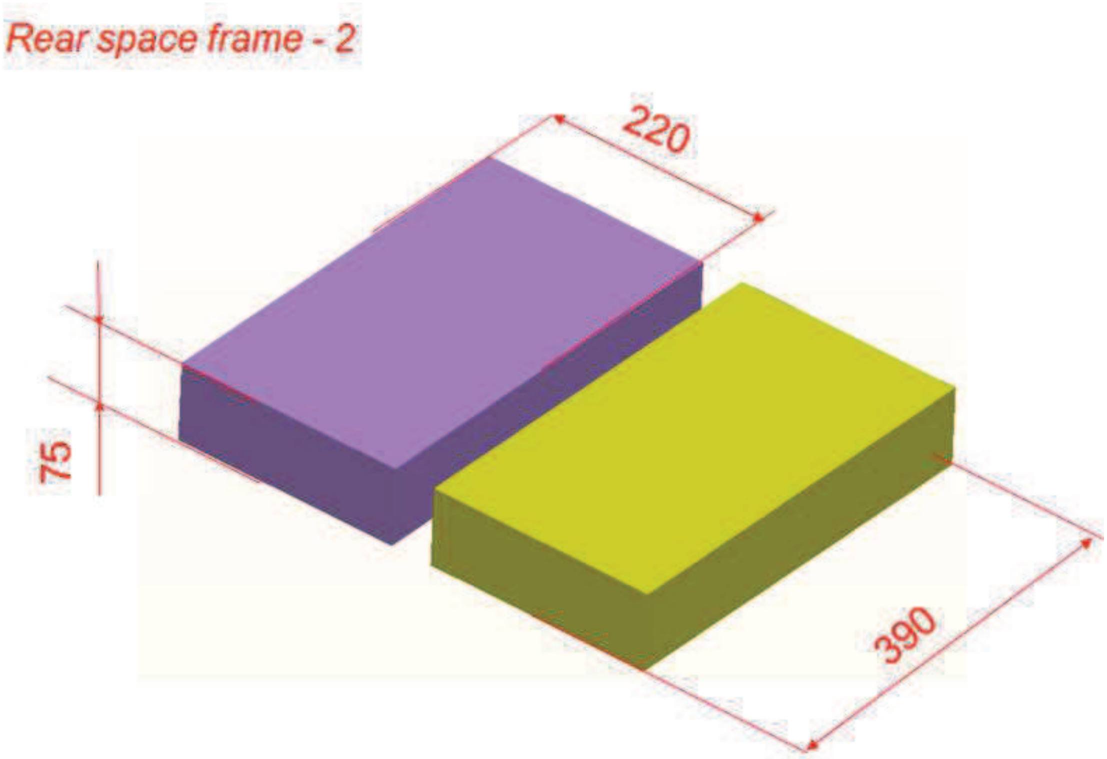


Figure 37: Rear space frame - 2 dimensions

Additional analyses on the installation of the pick-up coil on vehicle have been performed for the integration inside the prototype vehicle (an Iveco Daily) of the 50 kW systems.

Due to the wide dimensions of the systems, the rear part of the vehicle has been chosen as the proper one, in particular for prototype installation.

Furthermore, on the pure electric version of Daily, the rear part can host an additional battery pack.

In the following picture, the prototype installation space frame is shown.

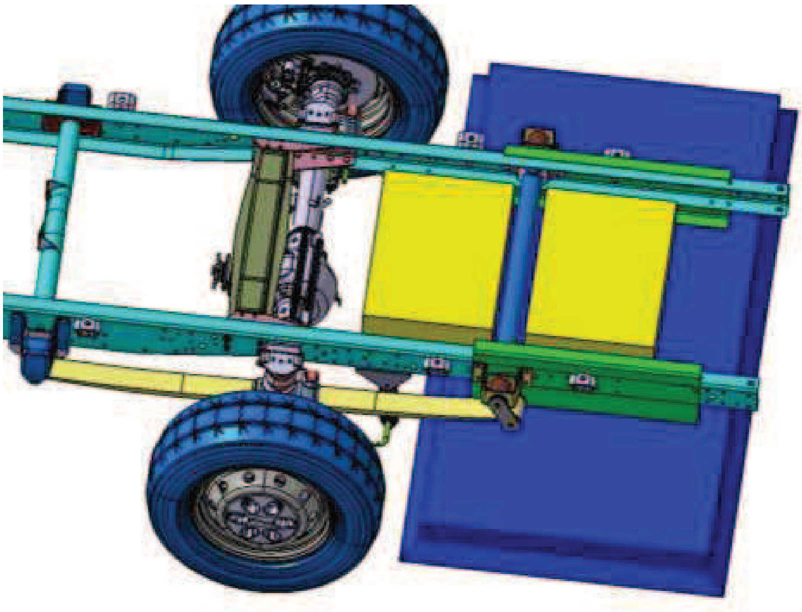


Figure 38: Pick-up coil installation on prototype

Installation on rear part of the vehicle for the prototype has highlight the need to take into account the slope angle, in order to allow vehicle to be able to move on slopes without obstacles, as highlighted in the following picture.

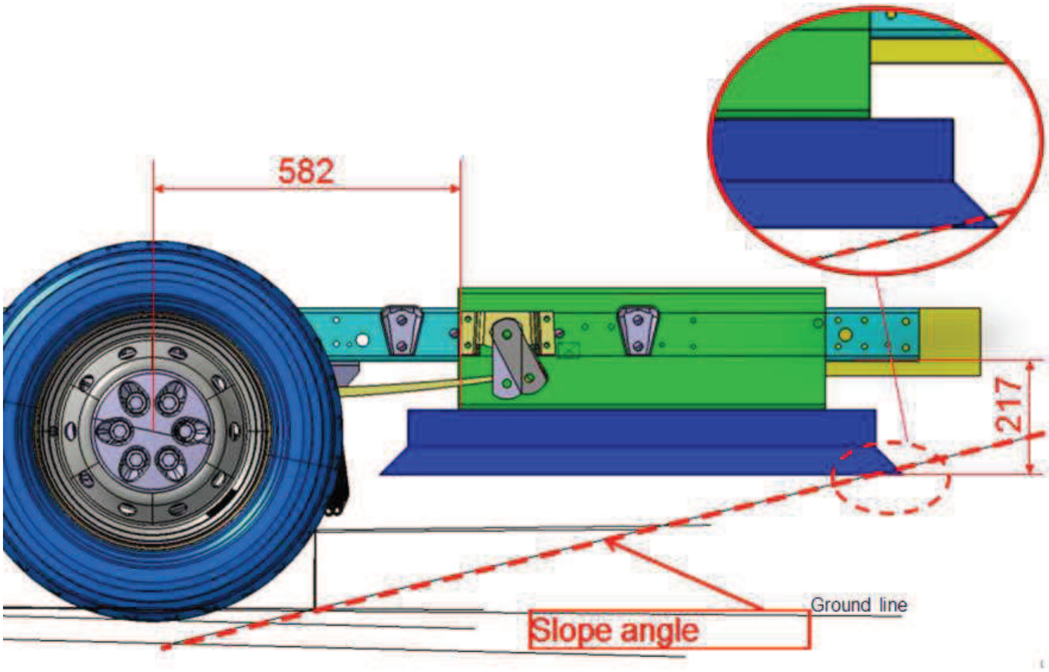


Figure 39: Slope angle analysis for pick-up installation

3.2 Strategies for the management of charging

To get a smooth transition to E-mobility and to support the commercialization of EVs, an EV infrastructure is the underlying foundation, which includes the basic facilities and services to support the operation of a large number of electric vehicles.

The basic infrastructure is already able to support E-mobility since the European electricity grid is highly developed; a more developed infrastructure concerning charging possibilities will be necessary to avoid the problem relating to operational range for EVs but also to increase the potential of EVs.

Many aspects can influence the E-mobility, it is necessary to consider the following aspects to develop a successful battery EV infrastructure:

- Availability of charging stations;
- Convenience of payment for charging;
- Standardization of EV batteries and charging;
- Regulation of clean and safe charging;
- Support from training and promotion;
- Impact on power utilities.

3.2.1 The Charging Infrastructure

The charging infrastructure, as well as the grid infrastructure, has to accompany the market penetration of electrified vehicles from the very beginning.
Infrastructure cost for charging are depending on place and type of charging. If the charging point is in a garage or an inside place investment is low, if the charging point is on the roadside the costs increases. In the case of a fast charge charging point costs will increase strongly. The impact of a fast charge point on the grid is greater (harmonics, load) than the slow charge, but there is no need to create a specific dedicated network reinforcing the existing one to ensure security of supply.
Implementing the V2G technology to stabilize the grid by using the car as energy storage device can increase the management costs from the grid side and can increase the vehicle costs for the bi-directional converter installation.

Besides the battery characteristics, charging of a battery depends, on the:

- Charging power (voltage/amperage)
- Charging time
- Charging technology

Charging power and time are strictly related; charging is commonly defined as Slow (or Regular) Charging, Fast Charging and Ultra-fast charging, according to power and time of the process, as highlighted in the next table.

Charging time	Power [kW]
Slow charging	3-6 (AC single-phase)
Fast charging	about 22 (AC tri-phase)
Ultra-fast charging	about 50 (AC tri-phase or DC)

Table 7: Charging time and power

For the wireless charging, and in particular for the en-route charging, the quantity of primary or base stations have to be multiplied (e.g. in front of traffic light) to give several cars one after another the opportunity of charging.
For the charge process a pairing over wireless LAN has to be carried out, to establish a link between base station and related pick up in car. For the power transfer then the exact overlapping between base station and pick up has to ensure. Misalignments can be balanced over the robustness of the coil. But in the stop and go traffic a sufficient tracking is necessary to align primary and secondary coil permanent.

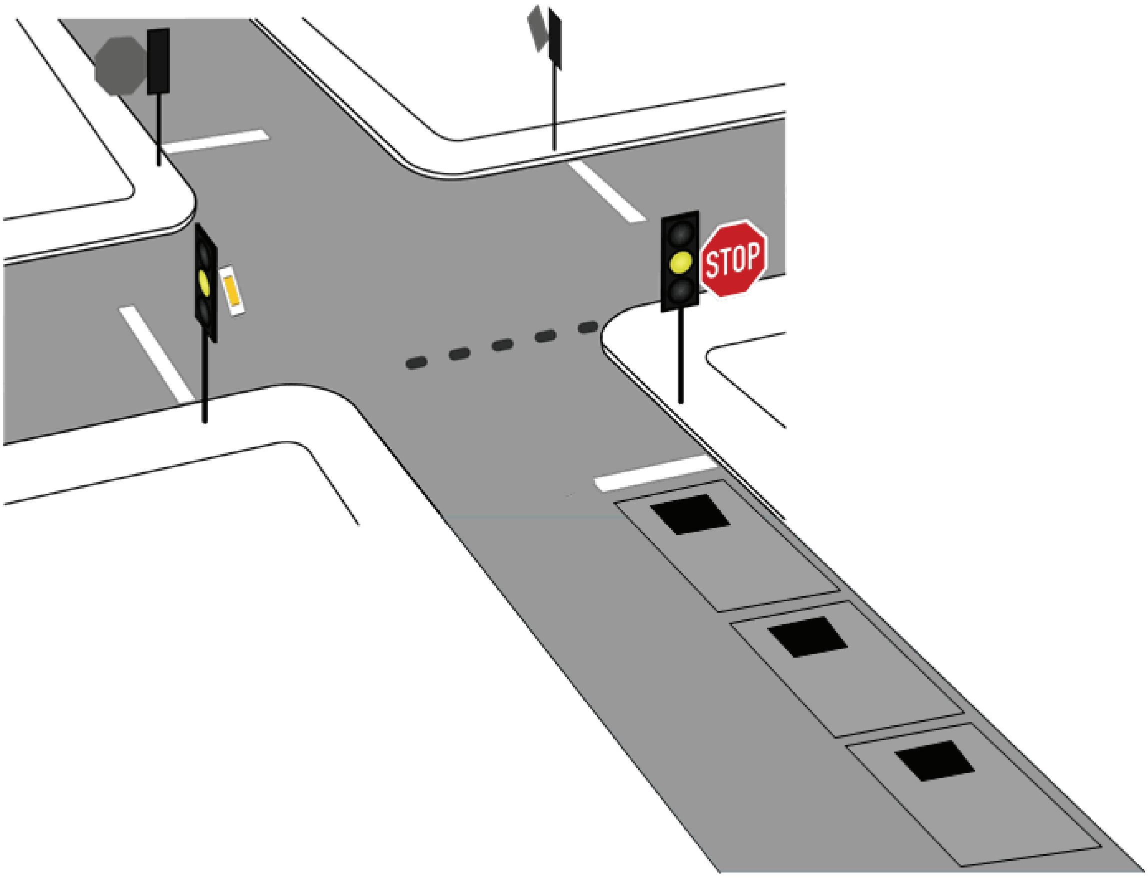


Figure 40: Example of installation of "en-route wireless charging infrastructure

Further considerations on charging duration and power are reported in

Annex 2.

3.2.1.1 **Charging technology**

Regarding the charging technology, today the following methods are possible:

1) Charge while stationary:

- Slow plug-in charging (AC)
- Fast plug-in charging (generally AC)
- Ultra-fast plug-in charging (AC or DC)

For the mid and long term, the possibilities for wireless (inductive) or contact charging have to be examined:

- Inductive charging: charging over inductive loops or inductive wire in the road, for example at bus stops, in front of traffic lights and in parking spaces;
- Contact charging: charging by direct contact, for example over the car number plate, on the roof of a city bus or through a pick-up connecting to rails in the road

2) Charge while driving :

- Inductive charging: charging over inductive loops or inductive wire in the road, for example on “green corridors” that are special lanes;
- Contact charging: charging by direct contact, for example over contact rail in road or by catenary system.

One other “innovative” electricity recharging systems can be considered. The idea basically being that an empty battery is swapped against a new fully charged one, an action that will only take a few minutes. This would be a “charging” procedure similar to fuelling an IC-car.

Battery exchange systems can provide very rapid replacement of depleted batteries with those that are fully charged, although many questions remain in regard to cost, extra required battery supply, compatibility of the battery systems used by different OEMs and replacement of new batteries with potentially older batteries.

One big challenge to be solved for the battery exchange system is the standardization of the batteries and the exchange technology. To consider are among others: the plug-in technology, the cell technology, standardization at cell level or at small package level, robotic exchange, etc.

Another question is if one should change empty batteries and charge them by fast charging or if one should change charged batteries. Fast charging could be important for battery exchange systems, since it increases the effective supply and lowers the number of batteries that must be kept in reserve to meet peak demand. The burden is the charging time of about 15 minutes. To change fully charged batteries is much faster but introduces challenges in storage space/capacity and safety. Battery technologies and licensing systems would also need to be compatible.

3.2.1.2 **Standardization**

It is important to avoid over-regulating in order to allow for innovation. The International Standards Organization (ISO), the International Electro technical Commissions (IEC), SAE, the Underwriters’ Laboratories (UL), and other organizations can play important roles in coordinating and setting standards.

Likely areas for standardization are:

- Plug types;
- Inductive and contact charging;
- Interoperability of charging systems;
- Recharging protocols;

- Communications protocols between cars and recharging infrastructure;
- The different electricity providers have to standardize the paying systems;
- The allocation of the vehicle to the plug socket must be defined;
- Regulations for public recharging that ensure safety with minimal administrative challenges;
- Battery recycling standards and regulations;
- Standards for battery packs (not for the cells);
- Utility regulations conducted by state/provincial authorities to ensure orderly participation in this market;

3.2.2 The Grid Infrastructure

3.2.2.1 Vehicle to Home, Vehicle to Grid

The idea of Vehicle to Home (V2H) and as second step Vehicle to Grid (V2G) system is to use the distributed and stored electric energy provided by the batteries of electrified vehicles. It is required an appropriate interface for the exchange of electricity and data between the vehicle and the grid, this is based on a business case involving the car owner, energy providers and grid operators, public authorities and utilities.

Before you can use the possibility of integrating the vehicle into electricity grid, some basic steps for the charging infrastructure must be taken. A basic step to facilitate the market success of electrified vehicles is the possibility for owners of electrified vehicles to charge the vehicle at home as well as during business hours.

Simultaneous or as fast follower to charging at home/business, the establishment of a smart charging infrastructure, the Grid to Vehicle (G2V) possibility to charge everywhere will take place. G2V infrastructure at parking structures, during business hours and shopping, are essentials for the market introduction and success of electrified vehicles. The fully integration of electrified vehicles to the grid, the V2H and V2G infrastructure needs some more technologies and investment.

Following this approach, “charge every time charging is possible”, wireless charging technology can facilitate EV integration into the grid, allowing easy power connections between vehicles and infrastructure.

The stored electricity of electrified vehicles could be used as back-up capacity to help to tune down unusual demand spikes, at home and in the grid. The bi-directional V2H system could be extended to a home assisting charging system. The possibility to be examined is to utilize the electric vehicle with large capacity battery as the electric power source of a home, connecting with energy management system which is to use energy more efficiently at residence.

The vehicle integration is not effecting the usage of the car while feeding electricity to the home steadily. It watches the amount of electricity left in the vehicle's battery constantly and defines the available amount to feed the home. From charging at low-load times up to the provision of extra control energy, plug-in vehicles could contribute essentially to the “shaping” of the energy load of the energy supplier. With these benefits they also support the enlargement of renewable energies in the electric grid, not easy to predict.

Grid powering from batteries could be very useful for provision of peak power and load balancing, but needs to be controllable by vehicle owners. There could be important limitations on how much depletion in battery capacity that vehicle users will tolerate (for example, the driver must be able to leave the car parked at work and be able to get home again).

Negative impacts on battery life must also be understood and minimized. With dynamic pricing, the EV owner would make a profit because the midday peak price offered for selling power during the afternoon should far exceed the cost of charging the battery at night. This is the final frontier and is an exciting idea, given all of the potential benefits.

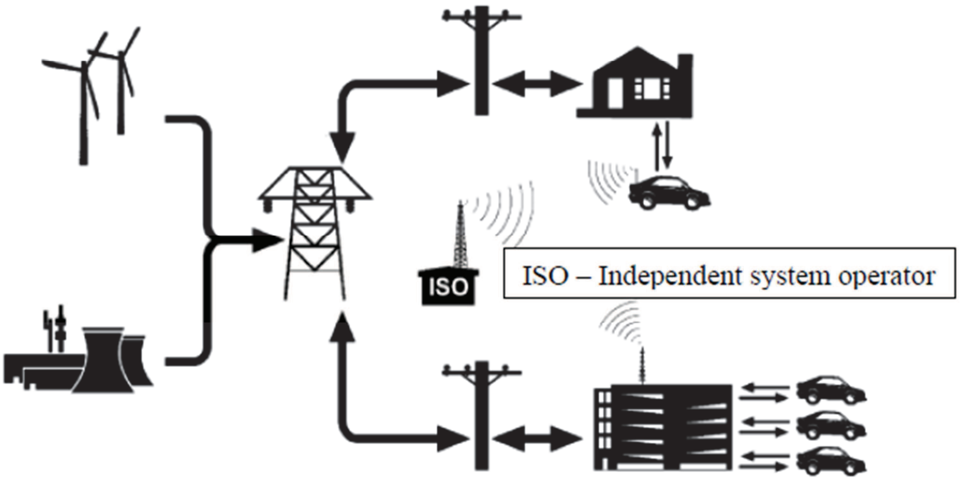


Figure 41: Concept of Vehicle to Grid.

The Vehicle-to-Grid technology will not be ready for the short term application. The relation of utility to expenditure is to examine, a lot of research is to be done to introduce this technology to the market, in a mid to long term perspective.

Main challenges today:

- Willingness of the vehicle owners to provide their battery for load-optimization and control energy.
- Battery technology: Development of long-life batteries for frequent charging and discharging. Moreover progress in battery capacity, weight and cost has to be achieved.
- Provision of a Smart Grid technology in dependence of load-speed (slow/fast) and place (city/landscape, at home/on a trip): Smart Grid and Smart Metering are essential components of V2G.

- Improvement of the communication infrastructure between network and operator, vehicle battery and load-infrastructure. The complexity of knowing the battery-load-condition, charging points, grid-load. When to charge the battery from the grid, when power could be delivered from battery to the grid.
- Fast charging needs a power even higher than 100 kW. This could not be carried out with the existing infrastructure. Fast charging infrastructure in parking buildings, at train stations, airports and shopping centres needs a connecting performance of several MW.
- The complexity of the distribution systems required: Two-way inverters would need to be developed and installed on a wide scale to bring V2G to completion.
- Billing infrastructure business models.

3.2.2.2 Smart Grid, the "Internet of Energy"

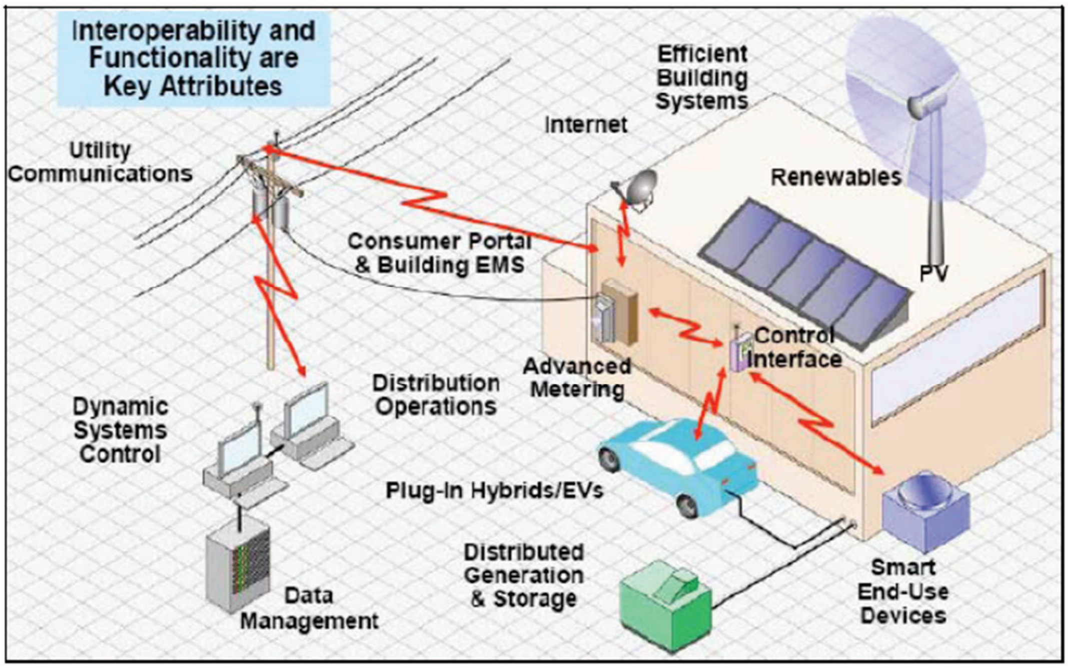


Figure 42: The Smart Grid.

As said before, the electricity grid and the electricity supply will change step by step to a Smart Grid. The present grid is strictly one-way, meaning that utilities have no way of measuring electricity usage with any more granularity than a monthly manual meter reading.

Information on consumption and return of electricity are needed in a very finer dissolution. The online control of consumers, decentralized production plants will allow an optimized regulation of the electricity grid.

Big companies from the ICT sector such as IBM and Siemens are presently collaborating with international energy suppliers for the corresponding hardware and software needs. Smart Grid is the answer for volatile production and open markets; which is a result of the collaboration of the ICT industry with the energy supply industry.

There is a great likelihood that the electric mobility will be an essential part of this "Internet of Energy". The possibility to use the car batteries as intermediate storage makes the plug-in electric vehicles an indisputable part of the Smart Grid. As part of the Smart Grid the "Smart Metering" hardware and communication network, the Automatic Metering Infrastructure (AMI), is a key enabler of the electricity valley filling approach.

Smart meters will measure electric usage in real-time and communicate this to the utility via radio frequency or broadband over power line technology. The role of smart metering should be fully explored via trials, with good information sharing. All forms of advanced charging systems (for example, vehicle-to grid power flow, day/night price differentials, restricted charging during peak demands) will require smart metering systems.

Smart meters and the wider smart metering system will offer:

- A common application layer and protocols allowing, through the "end-to-end" smart metering system, remote communication with compatible charge points and plug-in vehicles.
- The opportunity for energy suppliers to introduce time of use tariffs to incentivize off peak plug-in vehicle charging.
- The opportunity to meter and transmit plug-in vehicle usage separately, allowing energy suppliers to develop tariffs specially for plug-in vehicles.
- The ability to support dynamic Demand Side Management (DSM), actions that influence the quantity or patterns of use of energy consumed by end users, in conjunction with a future smart

grid, potentially allowing plug-in vehicle recharging to respond to signals from the grid. DSM must optimize the recharging of vehicles based on the available generation capacity and understanding which customers' vehicles will need to be fully charged at what time of day.

Additional analyses on the integration of Renewable Energies into the Smart Grid are described in

Annex 3.

3.2.3 Infrastructure models

Today there are some different ways to implement infrastructure, from advanced subscription models to more basic preparation of cities by installing charging poles and spots. An example was the Better Place Model that was a project in co-operation with Renault-Nissan in order to provide countries with EV charging infrastructure. Israel was the first country to commit to the Better Place plan. After that Denmark and Australia had also got involved in the project (Gilbert et al 2008). The Better Place idea was to provide all EV owners with a 220 V charge spot for garage or carport, this to enable charging during night. They would also provide additional spots around the city, parking lots and along urban streets. The most prevalent charge in their vision is the regular charge. One of Better Places major ideas was the battery swapping which basically mean that a depleted battery would be exchanged against a fully charged one (Better Place 2009). It was stated that Israel have committed to create a network of battery charging- and swap stations. The same amount was stated for Denmark with 150 of these being battery swap stations (Gilbert et al 2008). In this way they would have created a network of charging stations that would offer good conditions for EVs and PHEVs.
The Better Place model was a large scale commercial business model that had to be supported by governmental initiatives and actions from utilities.

It is more important to get more actors engaged in the market. Providing commercial businesses with charging possibilities will in the initial phase work more as advertising, but is important for the long term development. To provide parking lots with charging is a way to commit to development. The cooperation between Vattenfall AB and McDonalds is a good way to show that two large businesses are committed toward the EV development (Ibid).

In the same way European governments could show the same engagement and send signals toward society that EVs are a part of the future transportation. Important though will be that the actions taken by different companies and utilities will be focused on the same geographical area, for example a certain city.

3.2.4 Impacts on power system

EVs bring both good and bad influences on power system. Positively, the batteries of EVs can be charged at off peak periods or at night so that the overall power demand can be levelled and the utilization of power system facilities can be improved. Negatively, the EV battery chargers are non-linear devices which generate harmonic contamination to our power system, while the battery recharging of EVs at a normal or peak periods creates additional current demand burdens on our power system.

3.3 Development and validation of the simulation model

3.3.1 Introduction

A simulation model was required in order to evaluate the dynamic model of the vehicle at low speeds. Based on the forces generated by the magnetic coupling, the analysis is dedicated to the evaluation of the effects on the drivability during the activation and deactivation of the charging infrastructure.

The accomplishment of the task called for a simplified model of a prototype chosen for this work (an IVECO Daily commercial vehicle). For the sake of generality, the model was realized within the MATLAB environment. Generally speaking, simplified models of vehicle suspension behaviour can be grouped in three different types: quarter, half or full vehicle models.

Since this is a research project just getting started that aims to assess the impact of a new technology, dynamic inductive charging of electric vehicle, on a partially existing infrastructure, it was thought to realize a model that could remain as general as possible, in order to be adapted to any future needs.

The study of the vehicle performance has been conducted resorting to a full vehicle model which is based on one sprung mass (body of the vehicle) connected to four unsprung masses consisting of suspensions and tires.

The full vehicle model has a total of 7-degree of freedom: the sprung mass has 3-degree of freedom representing body bounce, roll and pitch movements, while the unsprung masses have 4-degree of freedom in vertical motions.

3.3.2 Dynamic model

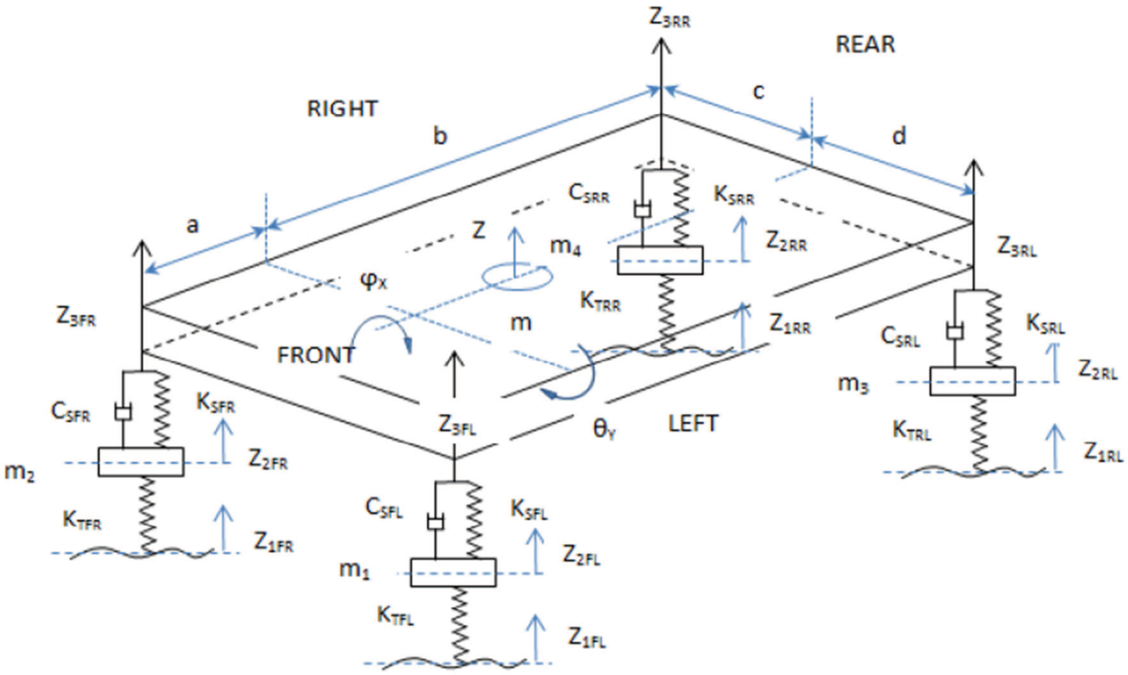


Figure 43: Simulation model with 7 degrees of freedom.

In the formulation of the model, several assumptions are made:

- vehicle is considered as a rigid body;
- aerodynamic effects are disregarded;
- the road is assumed to be level except for road disturbance;

- vehicle parameters such as tire stiffness, spring stiffness and damper coefficient are assumed to be time-invariant.

Based on the model with 7-degree of freedom represented in Figure 43, the dynamic of the sprung mass is defined by the following equation:

$$m_B\ddot{Z}_B = -F_{SFL} - F_{DFL} - F_{SFR} - F_{DFR} - F_{SRL} - F_{DRL} - F_{SRR} - F_{DRR} \tag{1}$$

where:

- m_B is the mass of the vehicle composed by chassis, engine, transmission and body;
- $\ddot{Z}_B$ is the body acceleration;
- F_{Sij} are the spring forces, where *i* stands for front (F) or rear (R) and *j* for left (L) or right (R).

The spring forces that act on the suspensions are given by the following equation:

$$F_{Sij} = K_{Sij} \cdot \left(Z_{Bij} - Z_{Uij}\right) \tag{2}$$

where:

- Z_{Bij} is the sprung mass vertical displacement;
- Z_{Uij} is the unsprung mass vertical displacement;
- K_{Sij} is the suspension spring stiffness.

The damping forces of the suspensions are given by the following equation:

$$F_{Dij} = C_{Dij} \cdot \left(\dot{Z}_{Bij} - \dot{Z}_{Uij}\right) \tag{3}$$

where:

- $\dot{Z}_{Bij}$ is the sprung mass vertical velocity;
- $\dot{Z}_{Uij}$ is the unsprung mass vertical velocity;
- C_{Dij} is the suspension damper coefficient.

The acceleration of the unsprung mass is given by the following relation:

$$m_{Uij}\ddot{Z}_{Uij} = F_{Sij} + F_{Dij} - F_{Tij} \tag{4}$$

where:

- m_{Uij} is the unsprung mass which includes wheel (rim and tire), suspensions and shock absorber, and braking system;
- $\ddot{Z}_{Uij}$ is the vertical acceleration at unsprung mass;
- F_{Sij} are the spring forces;
- F_{Dij} are the damper forces;
- F_{Tij} are the dynamic tire forces.

The dynamic tire forces are defined as follows:

$$F_{Tij} = K_{Tij} \cdot \left(Z_{Uij} - Z_{Rij} \right) \tag{5}$$

where:

- K_{Tij} is the tire stiffness;
- Z_{Uij} is the unsprung mass vertical displacement;
- Z_{Rij} is the road profile acting as the disturbance.

The pitch effect of the vehicle is defined by the following relation:

$$J_y \ddot{\theta} = -\left(F_{SFL} + F_{DFL} + F_{SFR} + F_{DFR} \right) \cdot a + \left(F_{SRL} + F_{DRL} + F_{SRR} + F_{DRR} \right) \cdot b \tag{6}$$

where:

- J_y is the moment of inertia about y-axis;
- $\ddot{\theta}$ is the pitch acceleration;
- a is the length of vehicle from the centre of gravity to the front end of the vehicle;
- b is the length of vehicle from the centre of gravity to the rear end of the vehicle.

Similarly, the roll effect of the vehicle is defined by the following relation:

$$J_x \ddot{\varphi} = -\left(F_{SFL} + F_{DFL} + F_{SFR} + F_{DFR} \right) \cdot a + \left(F_{SRL} + F_{DRL} + F_{SRR} + F_{DRR} \right) \cdot b \tag{7}$$

where:

- J_x is the moment of inertia about x-axis;
- $\ddot{\varphi}$ is the roll acceleration;
- c is the length of vehicle from the centre of gravity to the right end of the vehicle;
- d is the length of vehicle from the centre of gravity to the left end of the vehicle;

3.3.3 Dynamic excitation

The dynamic excitation in the model must take in account two main inputs: the road profile and the electromagnetic force.

3.3.3.1 Road Profile

The profile of the road infrastructure is one of the two main excitation inducers of the model; using the parallel track road model, a periodic stress can be determined by these relations:

$$\begin{aligned} z_{RL}(s) &= X \cdot sen(\Omega s) \\ z_{RR}(s) &= X \cdot sen(\Omega s - \Psi) \end{aligned} \tag{8}$$

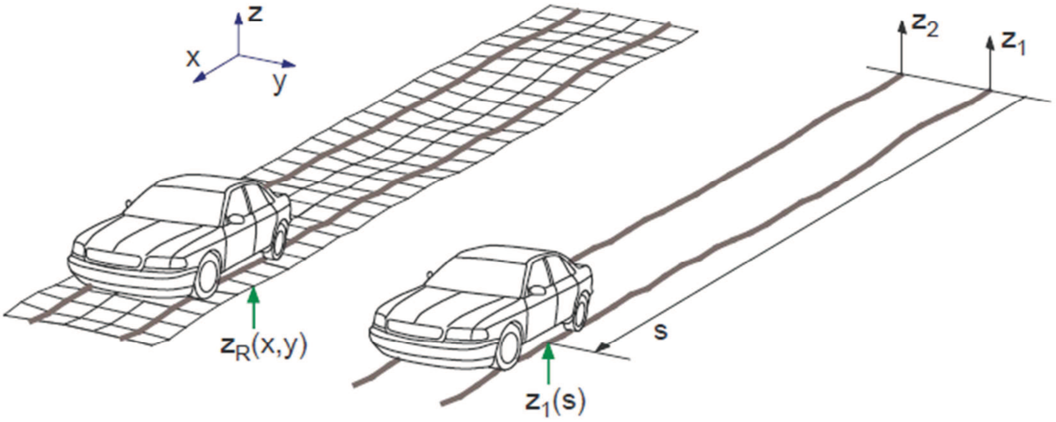


Figure 44: Parallel track road model

Where *s* is the path variable, whilst:

- z_R is the vertical displacement; z_{RR} indicates right side, while z_{RL} indicates the left side;
- X denotes the amplitude;
- Ω the wave number;
- Ψ angle that describes a phase lag between the left and the right track.

Moreover, the road profile can also be different for each tire, introducing four different functions for each single tire. Road profile can be defined by any kind of function; typically, white noise modulated by a sinusoid can be used as road profile as well.

3.3.3.2 **The electromagnetically induced force**

For the electromagnetic force interaction which is generated during the engaging and disengaging phases between primary and secondary coil, in the case of dynamic inductive charging, a parametric profile for the force has been chosen. Because the genesis of the electromagnetically induced forces may vary according to the recharging strategy in use, a parametric profile defining the input force was defined, in order to take in account a wide class of cases.

For instance, it is necessary to consider and know some parameters (as defined in Figure 45) such as:

- The shape of the transient function that represents electromagnetic force;
- Intensity of this electromagnetic force (A);
- Geometrical dimensions of primary and secondary coil (L_P and L_C);
- Primary and secondary coil position from the centre of gravity of the vehicle in exam;
- Centre to centre distance between different primary coils (i).

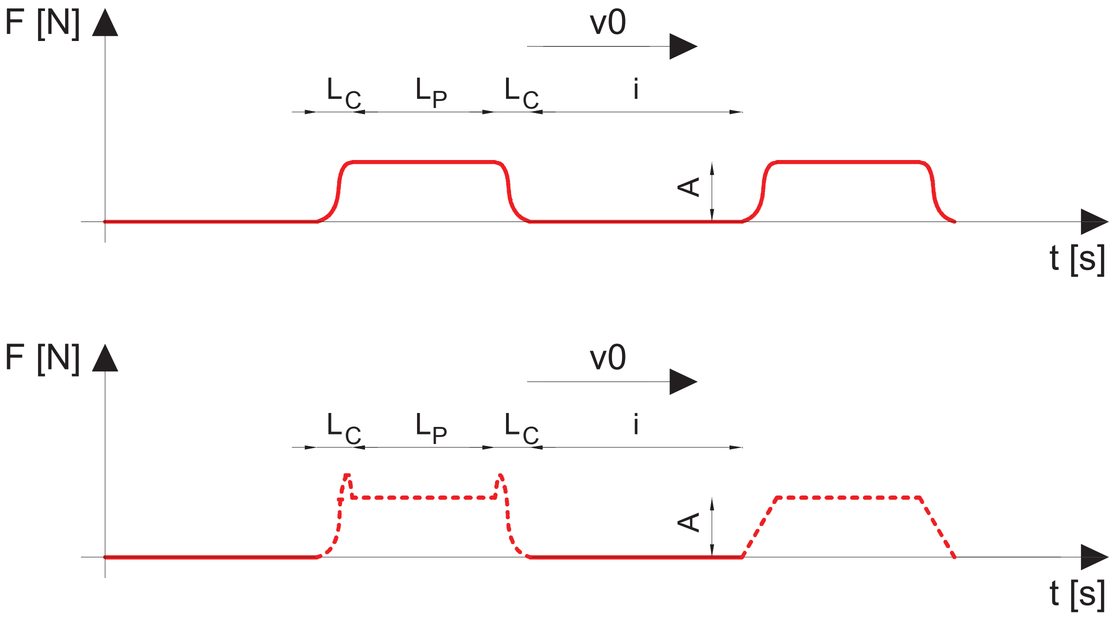


Figure 45: General profiles for the electromagnetic force.

3.3.4 Total input

The total input given to the system is the sum of the two input forces: the force due to the road profile and the electromagnetic induced force, only for degrees of freedom related to the four wheels.
For the total input, it is possible to consider different combination, such as:

- Road profile + Electromagnetic Force only on the two front tyres; if the secondary coil is positioned on the front side of the vehicle;
- Road profile + Electromagnetic Force only on the two rear tyres; if the secondary coil is positioned on the rear side of the vehicle;
- Road profile + Electromagnetic Force only on the two left tyres; if the secondary coil is positioned on the left side of the vehicle;
- Road profile + Electromagnetic Force only on the two right tyres; if the secondary coil is positioned on the right side of the vehicle;
- If the road profile input is much less than electromagnetic force, it can be neglected.

The simulations performed have taken into account the cases in which the total input is given by the sum of road profile and electromagnetic forces redistributed on the four wheels.

3.3.5 Numerical analysis for a case study

Figure 46: Commercial electric vehicle (Iveco Daily).

The input data are those relating to the geometrical and technical characteristics of the vehicle under study (an Iveco Daily), provided by CRF, which are listed in the table hereinafter. Several configuration have been investigated: a classic vehicle with empty and full load and the electric vehicle configuration with empty load and full load.

	Classic vehicle		**Electric vehicle**	
Parameter	**Empty load**	**Full load**	**Empty load**	**Full load**
m_B (sprung mass)	1924 kg	3160 kg	2410 kg	3646 kg
m_U (unsprung mass)	340 kg	340 kg	340 kg	340 kg
K_{Sij} (front suspension stiffness coefficient)	65000 N/m	65000 N/m	65000 N/m	65000 N/m
K_{Sij} (rear suspension stiffness coefficient)	130000 N/m	130000 N/m	130000 N/m	130000 N/m
C_{Dij} (front suspension damper coefficient)	5900 N·s/m	5900 N·s/m	5900 N·s/m	5900 N·s/m
C_{Dij} (rear suspension damper coefficient)	10000 N·s/m	10000 N·s/m	10000 N·s/m	10000 N·s/m
K_{Tij} (tire vertical stiffness)	400000 N/m	400000 N/m	400000 N/m	400000 N/m
J_x (moment of inertia about x-axis)	1171 kg·m^2	1446 kg·m^2	1250 kg·m^2	1516 kg·m^2
J_y (moment of inertia about y-axis)	5677 kg·m^2	9210 kg·m^2	7553 kg·m^2	11260 kg·m^2

a (length of vehicle from the centre of gravity to the front axis)	1.351 m	1.938 m	1.652 m	2.240 m
b (length of vehicle from the centre of gravity to the rear axis)	1.948 m	1.361 m	1.648 m	1.060 m
c (length of vehicle from the centre of gravity to the right end of the vehicle)	0.860 m	0.860 m	0.860 m	0.860 m
d (length of vehicle from the centre of gravity to the left end of the vehicle)	0.860 m	0.860 m	0.860 m	0.860 m
x-coordinate of the centre of gravity	1.351 m	1.938 m	1.652 m	2.240 m
y-coordinate of the centre of gravity	0.000 m	0.000 m	0.000 m	0.000 m
z-coordinate of the centre of gravity	0.910 m	0.740 m	0.885 m	0.700 m

Table 8: Type of vehicles considered in the simulations

The profile of the road, in this examples, was assumed to be a white Gaussian noise with N(0,1) then scaled by the amplitude *X*. Moreover it was assumed that front and back tires receive the same input:

$$\begin{aligned} z_{r1} &= X \cdot \sin\left(\Omega \cdot t\right) \\ z_{r2} &= X \cdot \sin\left(\Omega \cdot t - \Psi\right) \\ z_{r3} &= z_{r1} \\ z_{r4} &= z_{r2} \end{aligned} \tag{9}$$

Regarding variables that have been chosen reference is made to what has been previously described.

Using test values such as:

- Speed: $v_0 = 30 km/h$, $40 km/h$, $50 km/h$, $60 km/h$ and $70 km/h$;
- Time interval: it is calculated in relation with velocity and interval space, that will be describe later;
- Amplitude of the wave: $X = 0.0002m$
- Angle that describes a phase lag between the left and the right track: $\Psi = 0$

The electromagnetic force, in this example of simulation, can be used as initial input with the addition of the road profile, only for degrees of freedom related to the four wheels.

Parameters related to electromagnetic force taken into account for the simulation are the following:

- Speed: v_0=[30 Km/h; 50 Km/h; 70 Km/h];
- Longitudinal coil dimension: L_C=[0.4 m; 0.5 m; 0.6 m];
- Distance between two consequential coils: *i*=3 m;
- Magnitude of the electromagnetic force: A=[100 N; 500 N; 1000 N];

The values related to the intensity of the electromagnetic forces were chosen arbitrarily because, so far, no experimental values have been published on this aspect to date.

Simulations were performed taking into account all the possible combinations of the various parameters of the different input; some parameters, such as the distance between two consequential coils, were kept constant.

It is important to emphasize that this model has been realized as parametric as possible, in order to allow its application with any type of vehicle chosen as a prototype.

3.3.5.1 **Results**

The results of these simulations were collected in the following graphs which represent the vertical displacement of the main five degrees of freedom that are:

- Vertical displacement of the sprung mass;
- Vertical displacement of the front left wheel;
- Vertical displacement of the front right wheel;
- Vertical displacement of the rear left wheel;
- Vertical displacement of the rear right wheel;

It is also possible to plot pitch and roll of this vehicle, the sixth and seventh degree of freedom in this kind of model, but in this case they are less important than other degree of freedom.

In these tests all the possible parameters' combinations have been taken into consideration. Only the extreme values have been reported, as to assure the range as wide as possible.

Combinations that have been chosen are the following:

1) Amplitude of electromagnetic force and coil dimension are constant to vary the speed in two different situation: with the lowest values and with the highest values;
2) Velocity and amplitude of electromagnetic force are constant to vary the coil dimension in two different situation: with the lowest values and with the highest values;
3) Velocity and coil dimension are constant to vary the amplitude of electromagnetic force in two different situation: with the lowest values and with the highest values;

The full set of simulations with the assumed parameters is reported in Table 9. For brevity's sake only a part of the results are presented hereinafter (Figure 47 to Figure 50).

	Velocity [km/h]		Coil dimensions Lc [m]		Electromagnetic force magnitude A [N]	
	Case A	Case B	Case A	Case B	Case A	Case B
CASE 1	30	30	0.4	0.6	100	1000
	50	50	0.4	0.6	100	1000
	70	70	0.4	0.6	100	1000
CASE 2	30	70	0.4	0.4	100	1000
	30	70	0.5	0.5	100	1000
	30	70	0.6	0.6	100	1000
CASE 3	30	70	0.4	0.6	100	100
	30	70	0.4	0.6	500	500

	30	70	0.4	0.6	1000	1000

Table 9: Full simulation plan.

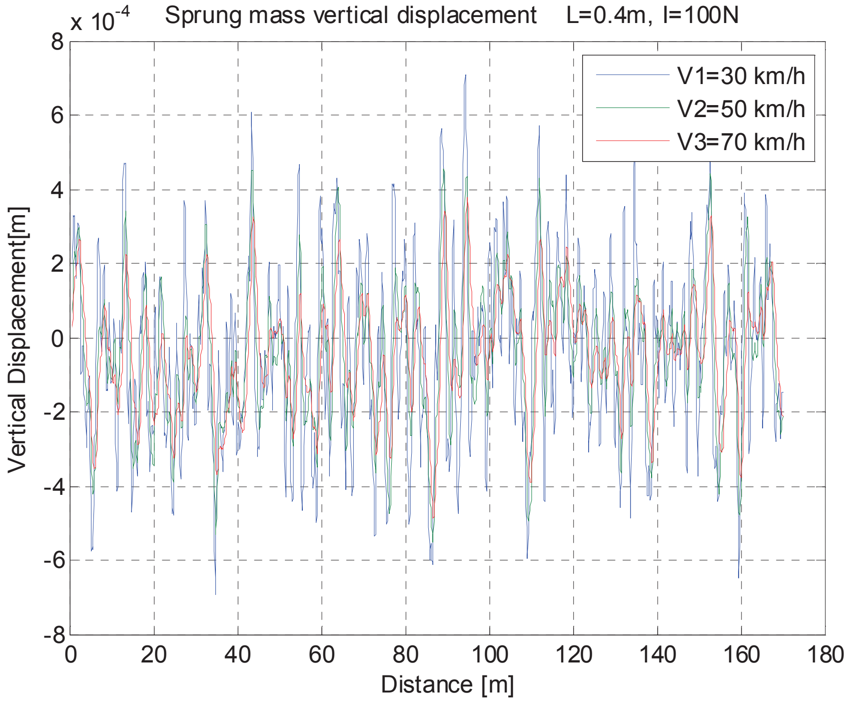


Figure 47: Sprung mass vertical displacement in case 1A.

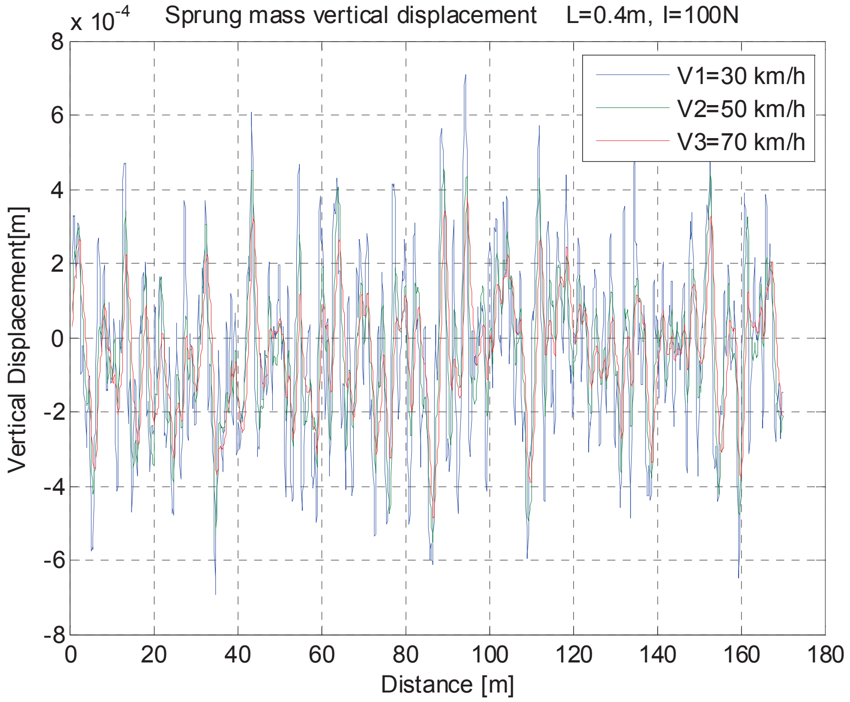


Figure 48: Sprung mass vertical displacement in case 1B.

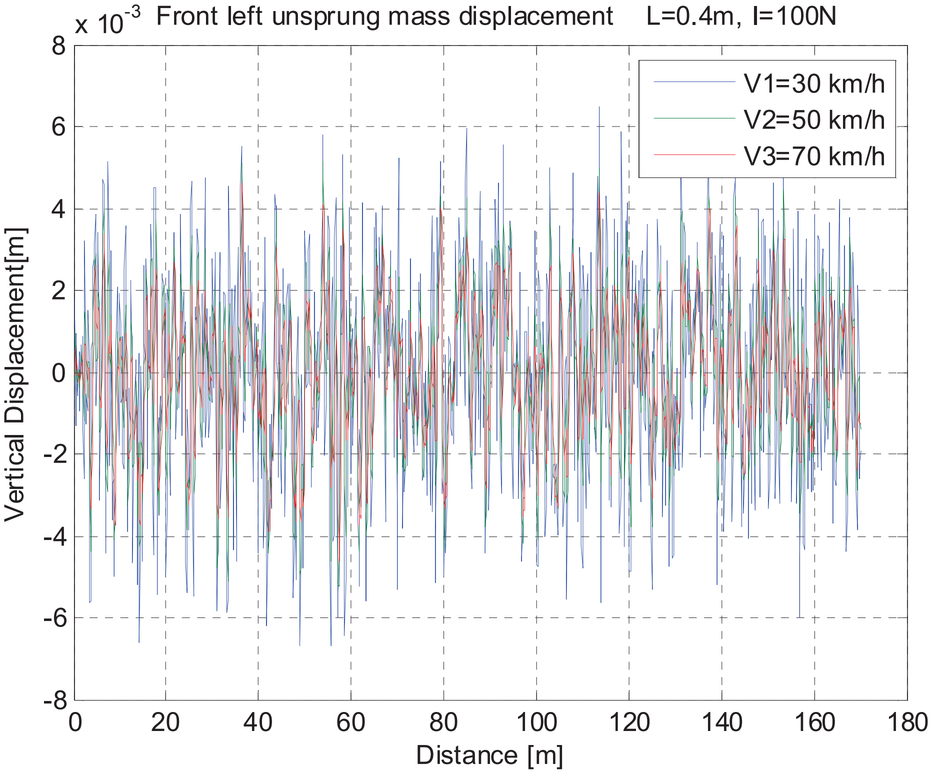


Figure 49: Front left wheel vertical displacement in case 1A.

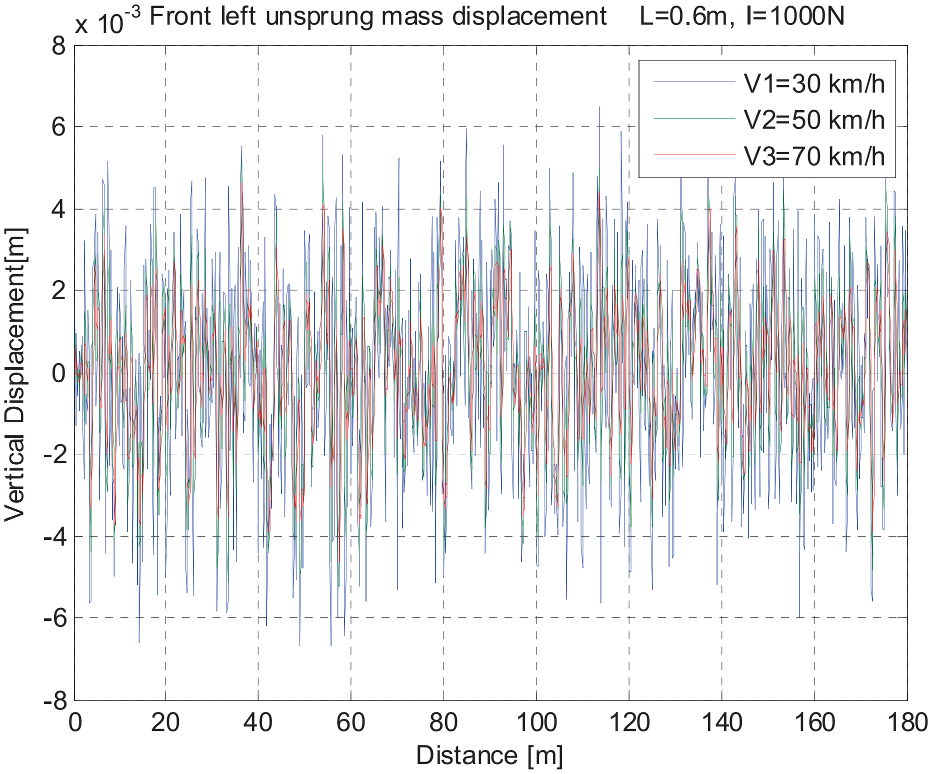


Figure 50: Front left wheel vertical displacement in case 1B.

3.4 Analysis of vehicle-infrastructure dynamics for system's optimization

3.4.1 Frequency response

A study in the frequency domain through the FFT algorithm has been conducted. This function may have many different uses, but in this specific case it is used to determine if the frequencies excited at certain speeds, or with a certain magnitude of the electromagnetic input force and with certain coil dimensions, may lead to resonance phenomena interaction with the natural frequencies of the existing structures (i.e. bridges, buildings, etc.).

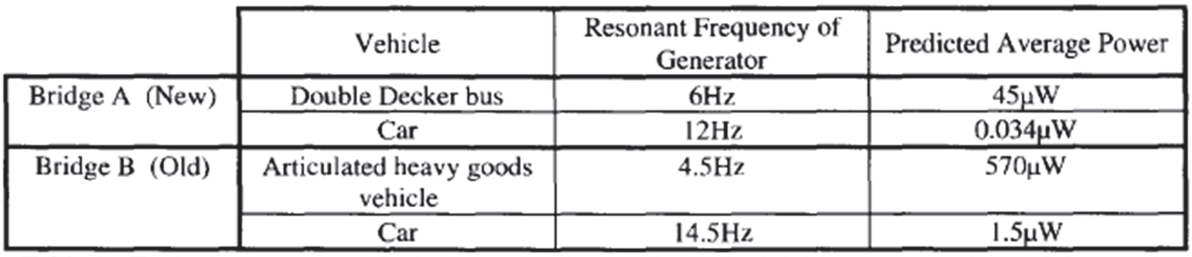
The FFT has been calculated for three different cases and we want to see how FFT change at:

1) different speed (V), but with intensity of electromagnetic force (I) and coil dimension (L) constant;
2) different coil dimension(L), but with velocity (V) and intensity of electromagnetic force (I) constant;
3) different intensity of electromagnetic force (I), but with velocity (V) and coil dimension (L) constant.

From the following results, it is possible to note that the maximum frequency achieved with these test values is about 10 Hz. These results can be compared with literature values, below there is an example.

Resonance frequency of rail bridges: about 14 Hz

Resonance frequency of road bridges: about 12 Hz



	Vehicle	Resonant Frequency of Generator	Predicted Average Power
Bridge A (New)	Double Decker bus	6Hz	45μW
	Car	12Hz	0.034μW
Bridge B (Old)	Articulated heavy goods vehicle	4.5Hz	570μW
	Car	14.5Hz	1.5μW

Where:

- Bridge A: Stradbroke Road Bridge, in Sheffield, UK; (light traffic density);
- Bridge B: Prince of Wales Bridge, in Sheffield, UK; (high traffic density).

It is important to note that the resonance frequencies known from the literature are similar to those resulting from the simulation (with the setup of parameters used).

The problem of resonance of some existing structures such as bridges, relative to this new technology (dynamic inductive charging), it is not to be underestimated and must be taken into account. For brevity's sake only a selection of cases are presented.

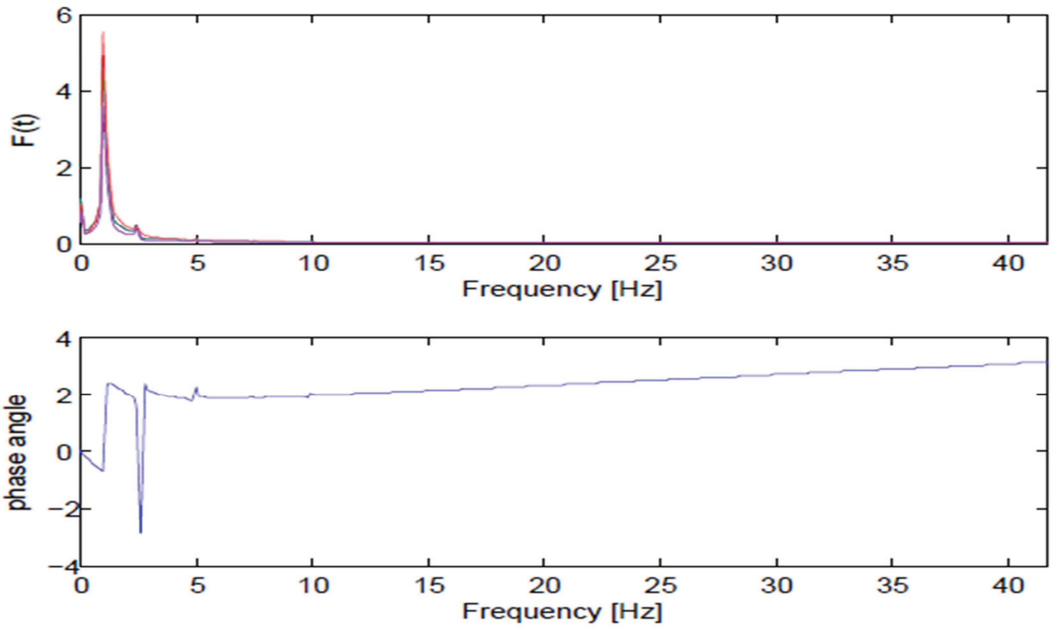


Figure 51: FFT(t) and phase angle, V=30km/h, case 1A.

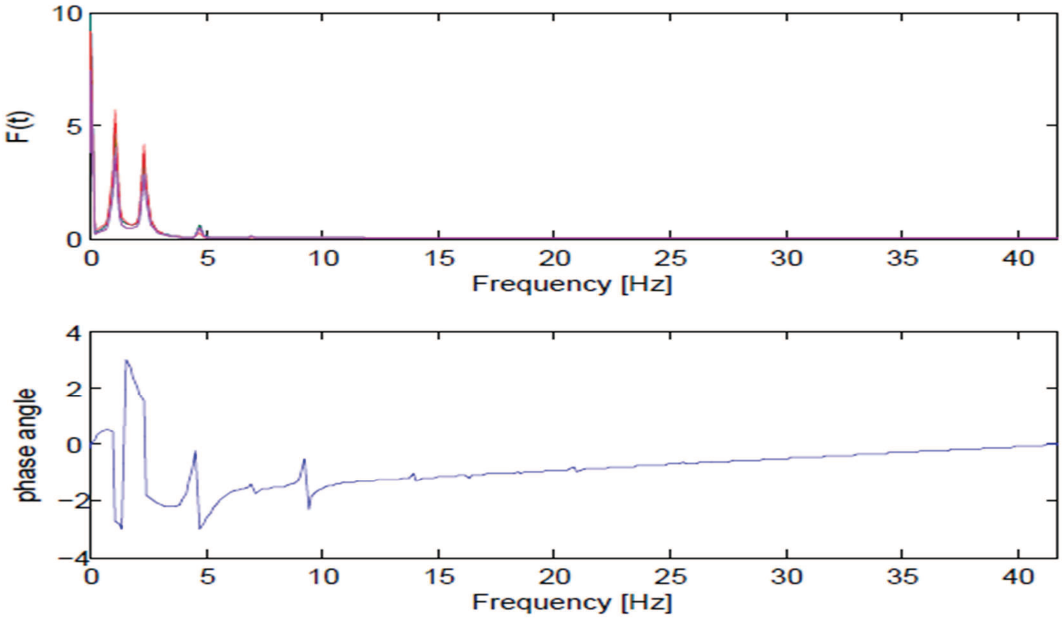


Figure 52: FFT(t) and phase angle, V=30km/h, case 1B.

3.4.2 Step and steer simulations

Step and steer simulations were carried out with the MSC Adams multibody simulation software for kinematic and kinetic analyses, which simulate the movement behavior of 3-dimensional mechanical systems realistically animated and can represent.

On the same vehicle of which the model has been described in the previous paragraph, were simulated some handling analysis, a dynamic maneuver (steer and release) with the help of MSC ADAMS program.

From this simulation have been obtained the values of some parameters, in the case of full load vehicle or without load vehicle, such as:

- steering wheel angle [deg];
- roll angle [deg];
- lateral acceleration [g];
- front and rear lateral forces [N];
- front and rear vertical forces [N];
- front and rear longitudinal forces [N].

The full plan of simulations is reported in Table 10, where it is possible to distinguish between two different velocities (40 and 60 km/h) and three different levels of steering (20°, 40° and 60°). A selection of results is presented hereinafter.

	Velocity [km/h]	**Levels of steering**
Full load	40	20°; 40°; 60°
	60	20°; 40°; 60°
No load	40	20°; 40°; 60°
	60	20°; 40°; 60°

Table 10: Simulation plan for steer and release maneuver.

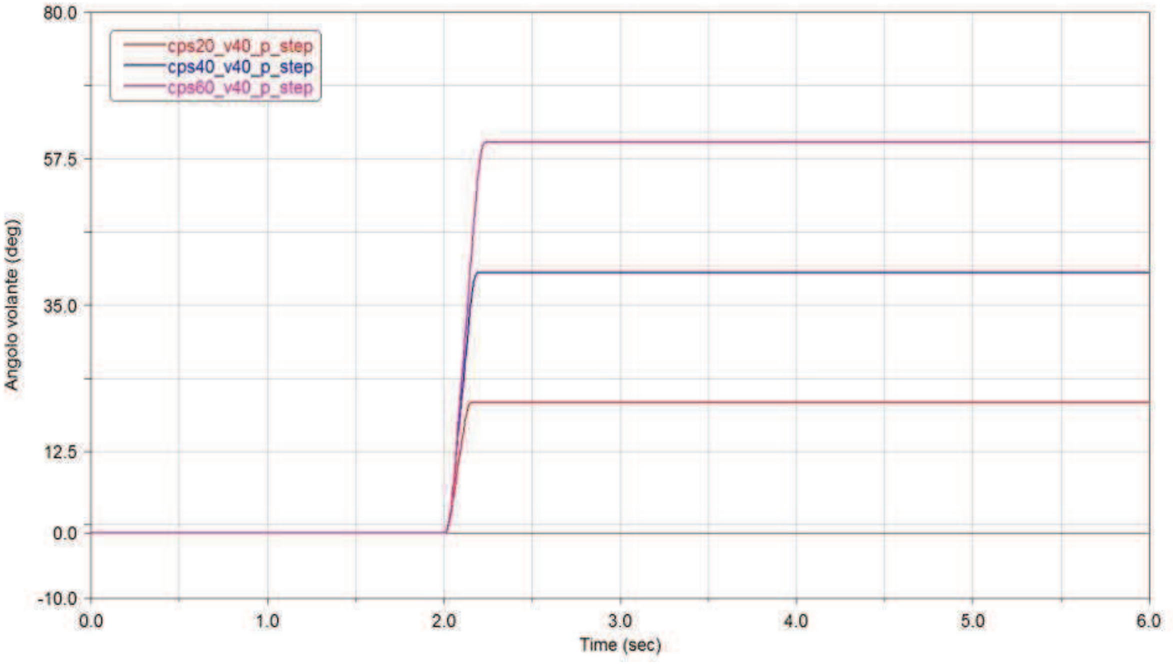


Figure 53: Steering wheel angle (deg), V=40km/h, full load vehicle.

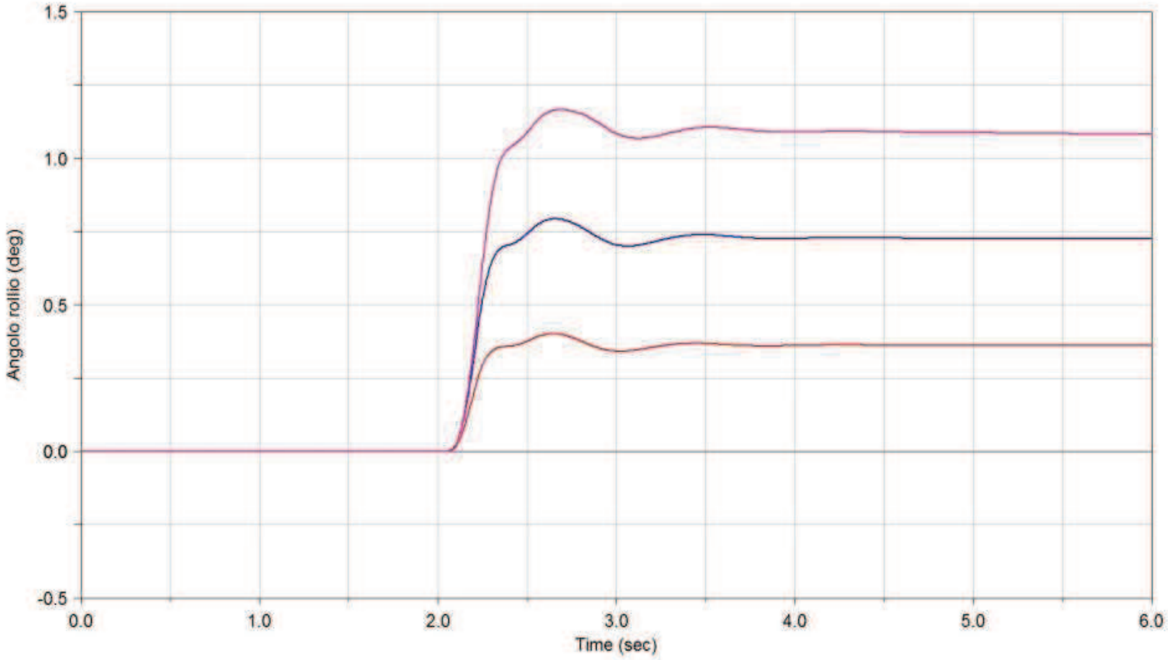


Figure 54: Roll angle (deg), v_0=40km/h, full load vehicle.

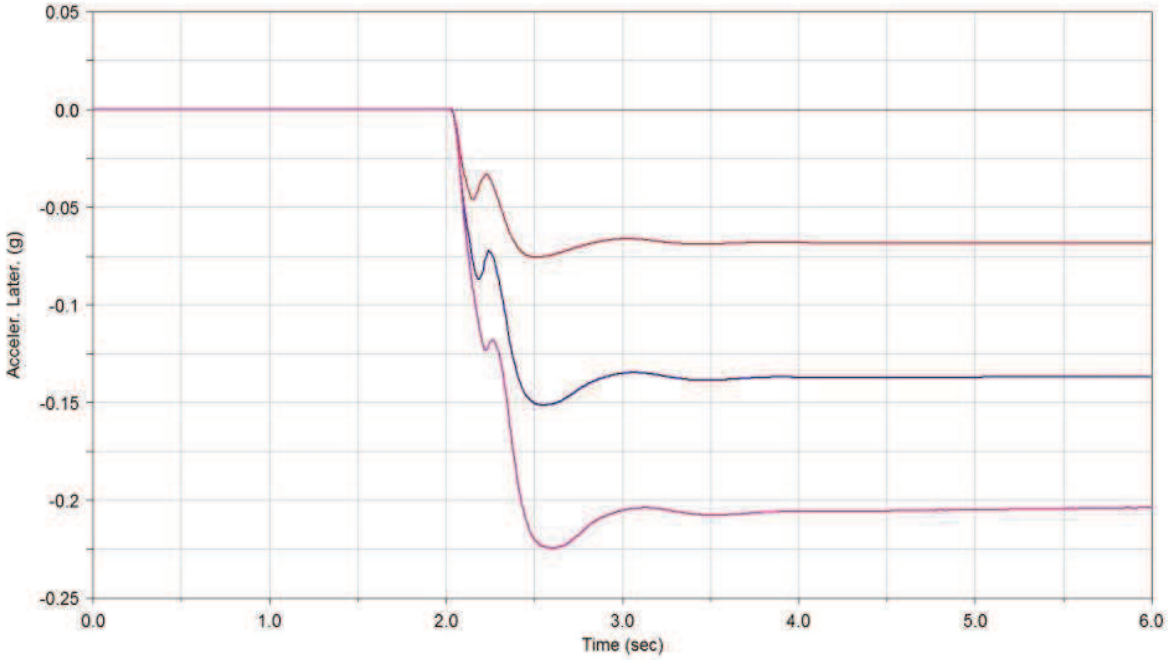


Figure 55: Lateral acceleration [g], v_0=40km/h, full load vehicle.

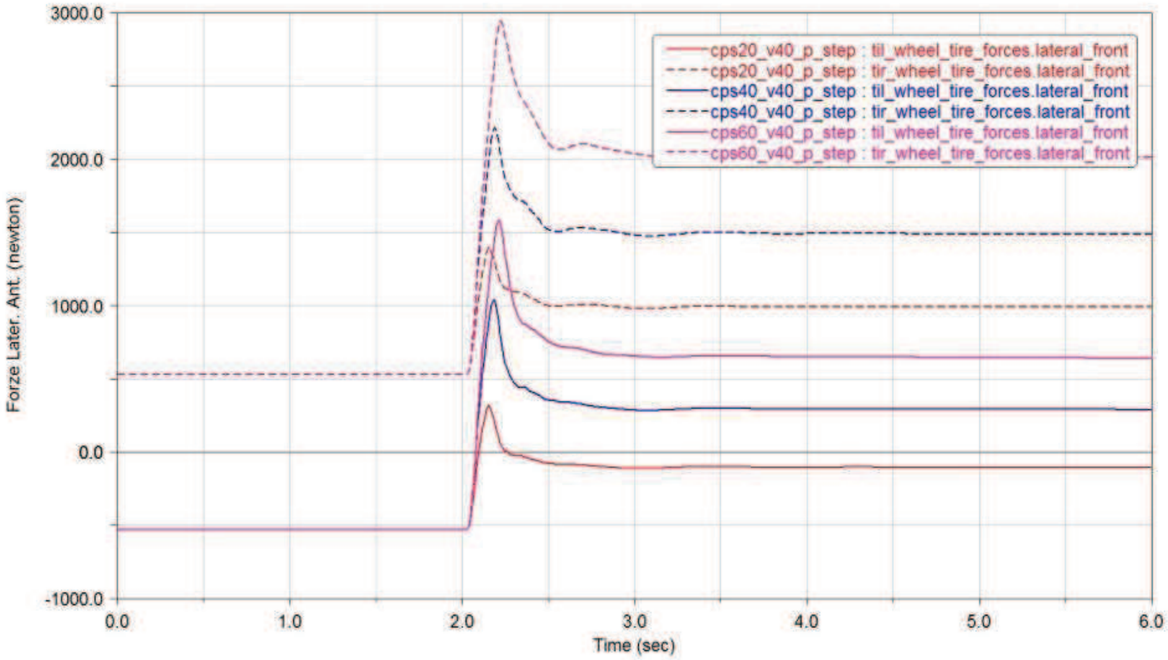


Figure 56: Lateral forces on front side (N), v_0=40km/h, full load vehicle.

4 Impact on the vehicle E/E Architecture

4.1 Analysis of the impact/modifications of Pick-up installation on vehicle

4.1.1 Car, Light commercial vehicle

The pick-up secondary coil of a wireless charging system has an impact on the electrical and electronic architecture of a standard car or light commercial vehicle.

The main differences in comparison with higher power demand architectures, described in the next paragraph, are mainly related to the power of the system and to the different voltage levels (generally lower than 400V for a car and a light truck, even over 700V for a bus or a truck).

In the following figure, an overview of electric architecture for the Unplugged prototype is shown.

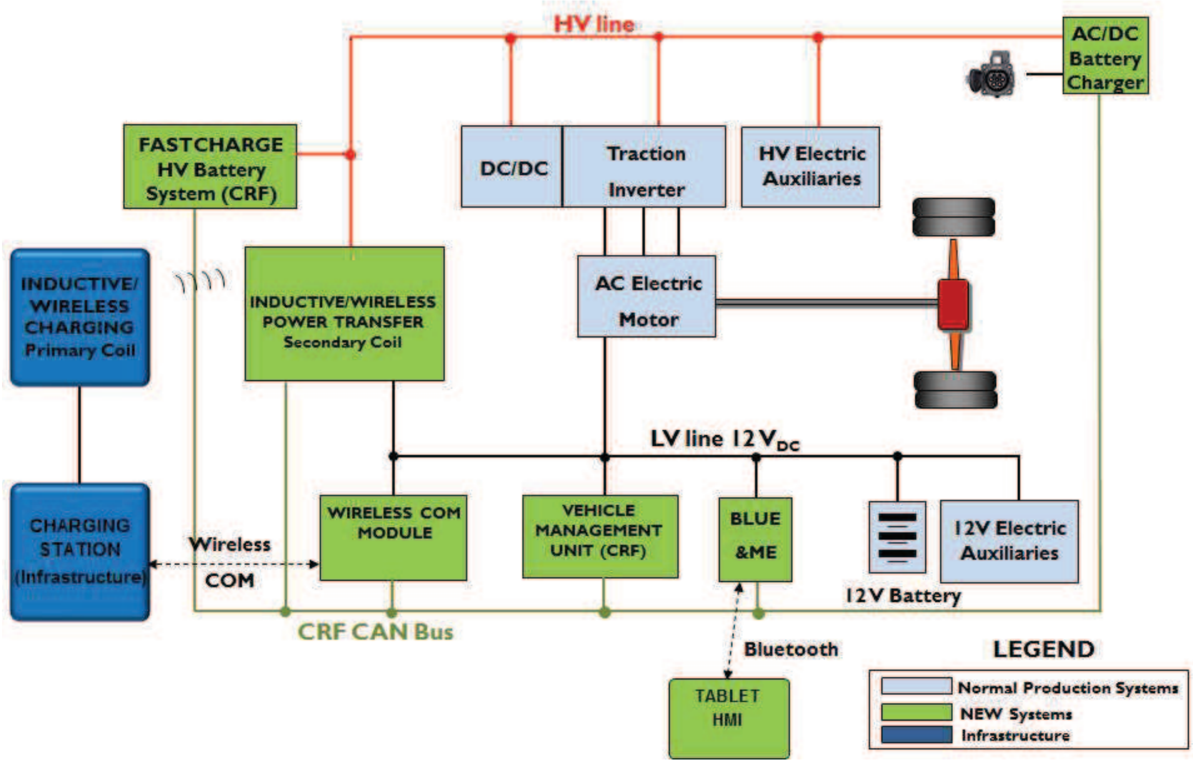


Figure 57: E/E Architecture

As highlighted from the picture, that represents the prototype explanation, it is possible to describe the new component necessary to deal with the issues related to the installation.

The pick-up of a wireless charging system interacts with the infrastructure through the primary coil for the power transfer and through the communication modules for the information and data exchange necessary to manage charging process.

On the vehicle the impact is evident in the connection between the secondary coil system, that comprises the power electronics, and the battery system.

In order to allow an easy connection, safe and compliant with automotive standard, a possible solution is the use of a dedicate power connection, as shown below.

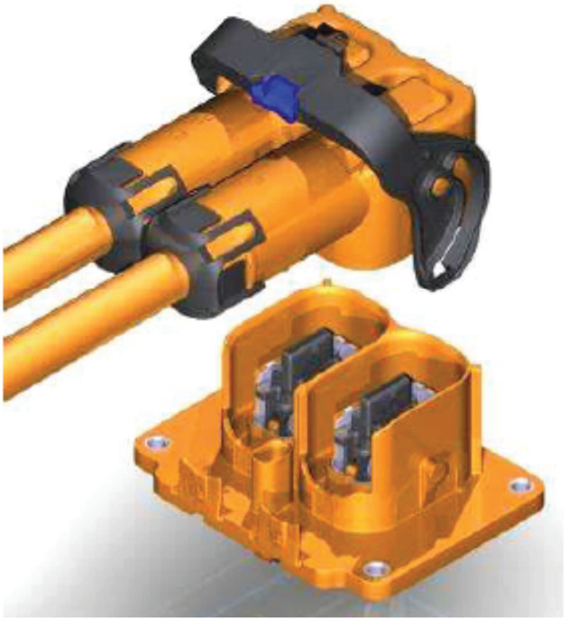


Figure 58: Connector for interface with pick-up coil (Kostal connector)

Further consideration can be made on the interaction with the HV DC bus.

Introduction of additional power electronics (with capacitors and inductors) can vary the behavior of DC bus, especially during the pre-charge phase of the HV DC bus, normally managed by the BMS through its internal pre-charge relays and resistors.

Another aspect is the need to provide a mechanism to safety manage possible issues on DC bus.

Normally battery pack comprises internal fuses and relays to manage safety issues, but to avoid an over-voltage due to charging system, for example in case of missing or wrong communication, it could be necessary to introduce a self-mechanism to limit the voltage to a value that does not damage the battery pack.

To implement this mechanism a possible solution is to install on the DC bus a resistor that automatically cuts the charging, when the voltage exceeds the set value and dissipate exceeding power in the braking resistor.

In this way, the charging control loop of the wireless system has enough time to reduce or completely cut the power.

Figure 59: Example of a braking resistor

4.1.2 High-Power demand - Bus

“High-Power Demand” vehicles in this context relate to vehicle types that have significantly higher average and peak propulsive power requirements than the more common cars that have been the focus of previous chapters. In most cases this is a direct result of the vehicle's increased size and/or weight.

Into this category fit:

- Transit Buses;
- Trucks; and,
- Vans.

The suitability, and associated success, of hybrid and/or electric drive-trains in these vehicles is very dependent on the duty cycles of the vehicles involved, and the likelihood of taking advantage of regenerative braking events. It is for this reasons that hybrid technology is being applied extensively to transit buses - they operate on predictable routes of heavily 'stop\start' duty cycles, providing regeneration opportunities, as well as the opportunity for engine-off time.

This chapter will focus on the inclusion of inductive charging system to existing diesel-electric hybrid vehicles, as these are the types of vehicles already design and produced by BAE Systems and Volvo.

4.1.2.1 Similarity to lower power demand vehicles, e.g. Cars.

The principles for hybrid driven vehicles in these higher power demand areas is not significantly dissimilar from those of the smaller vehicles - the majority of the considerations that must be made on the smaller vehicles when including an inductive charging system, also apply to the higher power demand vehicles. These include:

- Vehicle HMI Improvements
    - New driving modes – The inclusions of static en-route charging brings with it the need for additional driver information regarding status of the inductive charging system, along with any HMI regarding the alignment and usage of the inductive charging system.
- Connectivity
    - Wireless connection to charging infrastructure is needed. Security measures will be vital to ensure the inductive charging system is only used by approved vehicles, and measured and charged for accordingly.
    - A number of higher power demand vehicle types (e.g. transit buses), may offer easier to control security, as a result of vehicle movement restrictions (e.g. bus only traffic lanes).
- Electrical Performance

  - Electrical safety standards and safety protocols also apply to higher power demand vehicles. The higher voltages used, and distributed nature of the systems, once fitted to the vehicle; often make meeting these specifications more difficult.
- EMC (Electro-magnetic compatibility)
  - Higher power demand vehicles must meet the same standards and EMI limits as all EU vehicles. However, the higher power levels (current magnitude and switching times determines conducted emissions) make the requirements harder to meet. Additionally, the wider distribution of system components and resulting longer cable lengths make it difficult to shield and prevent emissions.

4.1.2.2 Primary Considerations for Higher-power Demand Vehicles

The majority of considerations that must be made specifically to this type of vehicle relate directly to the vehicles increased size and weight, including:

Voltage and Power Levels

The larger hybrid systems can run at higher electrical bus voltages than their car counterparts.

The BAES HybriDrive System (HDS) HV DC Link runs at a nominal 640 V DC. The vehicle-side inductive charging unit system will need to integrate with this voltage level, whether this is directly or via an additional converter unit.

The BAES HDS currently provides two different generator/electrical motor combinations, a ~145kW system (used on smaller buses, weighing around 20,000Kg laden) and a larger ~200kW system (used on larger, often articulated vehicles, of around 30,000Kg laden). These power levels are vastly higher than those seen within car applications.

The inductive charging system currently being investigated as part of the UNPLUGGED project is rated at 50kW peak. This is only a 3rd of the peak power of the smaller BAES HDS, before any induction or electrical conversion losses are considered.

Charging using this level of power at stationary points (e.g. bus-stops) would improve fuel economy, but will not be sufficient to negate the need for an on-board power-plant. It would be able to supplement, but not replace, the existing Internal Combustion Engine (ICE).

System Operation and Power Switching Logic

If the ICE cannot be removed completely, then the issue of the dual sourcing of energy must be considered. With both an ICE and an inductive charging unit present, electrical power may come from two locations at once.

The interrelationship between the ICE, Inductive Charging Unit and the Hybrid System's Battery must be managed carefully, to ensure that they do not interfere with each other, or adversely affect the operation of the system.

Electrical safety considerations and assurance that the behaviour of the combined system is sensible during potential fault conditions is of particular importance.

Physical Size, Placement and System Distribution

The majority of transit buses are low-floored, and also offer controllable suspension that allow the vehicle to 'kneel', and lower the floor further for easy access at bus-stops. This may restrict the amount of space available below the vehicle for the inductive charging coil and supporting elements. If space is limited, larger units may have to be moved to the engine-bay (which brings with it significantly higher operating temperatures), or the vehicle's roof.

In single-deck applications, e.g. see Figure 60 for a Volvo hybrid bus, the majority of hybrid drive-train components are mounted upon the roof of the vehicle. This includes the battery, electrical conversion units, controllers and cooling packs.

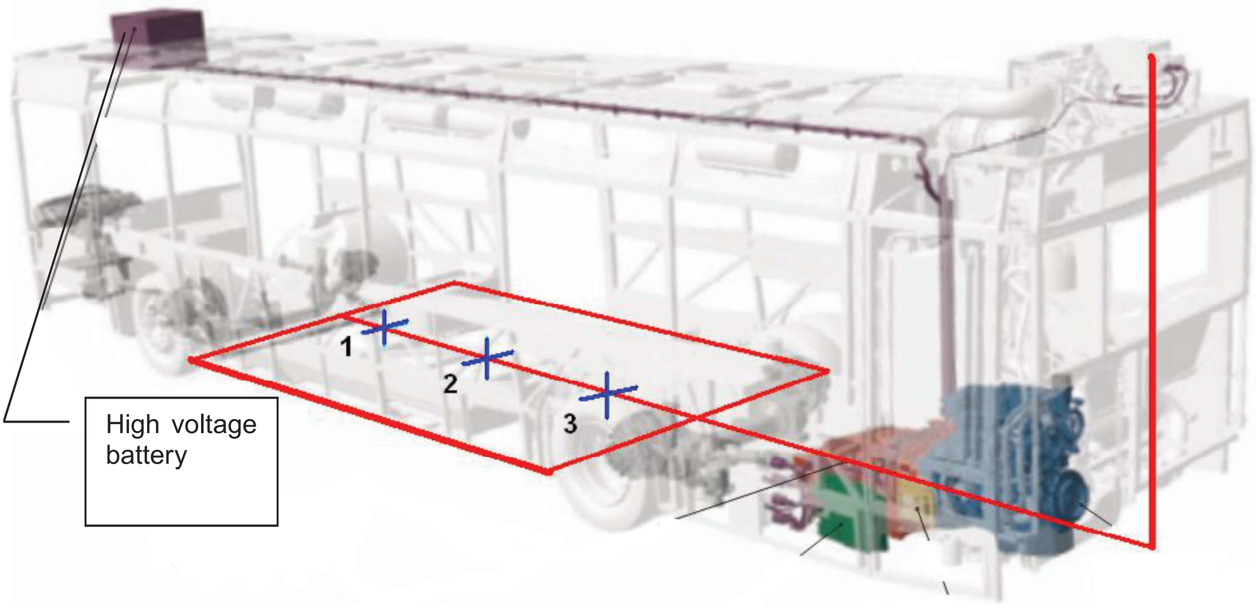


Figure 60: VOLVO 7700 Hybrid Bus

If the inductive charger systems are located in the chassis/under the floor of the vehicle then cable routing to the rest of the propulsion system may be long in length and complex to fit (HV cabling is often thick with a restricted bend radius, making its routing non-trivial).

Duty Cycles and Infrastructure Usage of Transit Buses

Transit buses duty cycles will often involve many frequent, yet short, vehicle stops as they halt to let-off and pick-up passengers. However, two considerations should be made.

Short Stop Time

Whereas a car could utilise a static inductive charging point for a substantial amount of time (e.g. when parked in a space outside a shop, perhaps > 15 minutes), transit buses are likely to be stationary for less than one minute, (a London bus-stop duration is < 30 seconds, often as low as 10 seconds).

To make use of each and every short duration vehicle stop, inductive charging technology would have to be installed at all stops, which could be costly.

Unpredictable Stop Locations

While transit-buses follow pre-determined routes, their stop locations can be unpredictable. They are often impeded by other vehicles, and may only stop in the vicinity of the bus-stop, possibly not close enough, or accurately positioned enough to make use of the inductive charging coil located within the road.

4.2 E/E integration: communication with vehicle ECUs

Especially for wireless en-route charging it is evident that communication between the vehicle and the infrastructure has to be wireless, too. Thus a wireless communication system in the EV is required to play the role of communication link (gateway) between charging management and other vehicle systems on the one side and the infrastructure on the other side.

For all wireless charging possibilities (e.g. en-route and static charging) should be used the same communication system (hardware and procedure).

The wireless data connection itself has to fulfil at least following requirements:

- Quick establishing of a stable wireless data transmission even with a large number of frequently changing communication partners.

- Bandwidth adequate to be able to send all necessary data in time.
- Support of direct data link ranges of min. 10 m and up to 50 m in open range conditions (outside buildings)
- Safe and unambiguous identification and authentication of communication partners inclusive spotting of EVs resp. infrastructure facilities.
- Fault tolerant as well as flexible (changing environment, different protocols) wireless link with data encryption capability and safety against manipulation and hacking

Via wireless data connection all necessary data relevant for en-route charging have to be exchanged between EV and infrastructure. For this purpose it’s necessary to connect (directly or indirectly) the communication system to all systems involved in wireless charging of the EV. This can be done by extending existing vehicle busses (e.g. CAN, Flexray, Ethernet, ...) or by implementing new connections.

Regarding power management of the communication system a proposal can be the following:

In phases without need for any wireless data connection the communication system could switch off wireless broadcasting at first. To save energy in longer inactive phases a sleep or power save mode should be supported.

In certain phases the communication system can be switched off completely by power management of the EV. However it must be possible to wake it up in all cases and situations if wireless data connection is needed. This could include e.g. a long term parked EV.

To ensure stable wireless data transmission sufficient field strength is required. In order to achieve this objective maybe multiple antennas are required. The antennas must be placed in proper positions in the EV (and infrastructure).

Finally it should be taken into account that the wireless data connection and the communication system possibly will be used for other use cases, too (e.g. navigation, infotainment, communication, and internet). Even simultaneous operation of several use cases is almost certain. In these cases additional requirements, such as increased data bandwidth, have to be considered.

On the basis of ISO 15118, a proposal of wireless communication process is showed in the next figures.

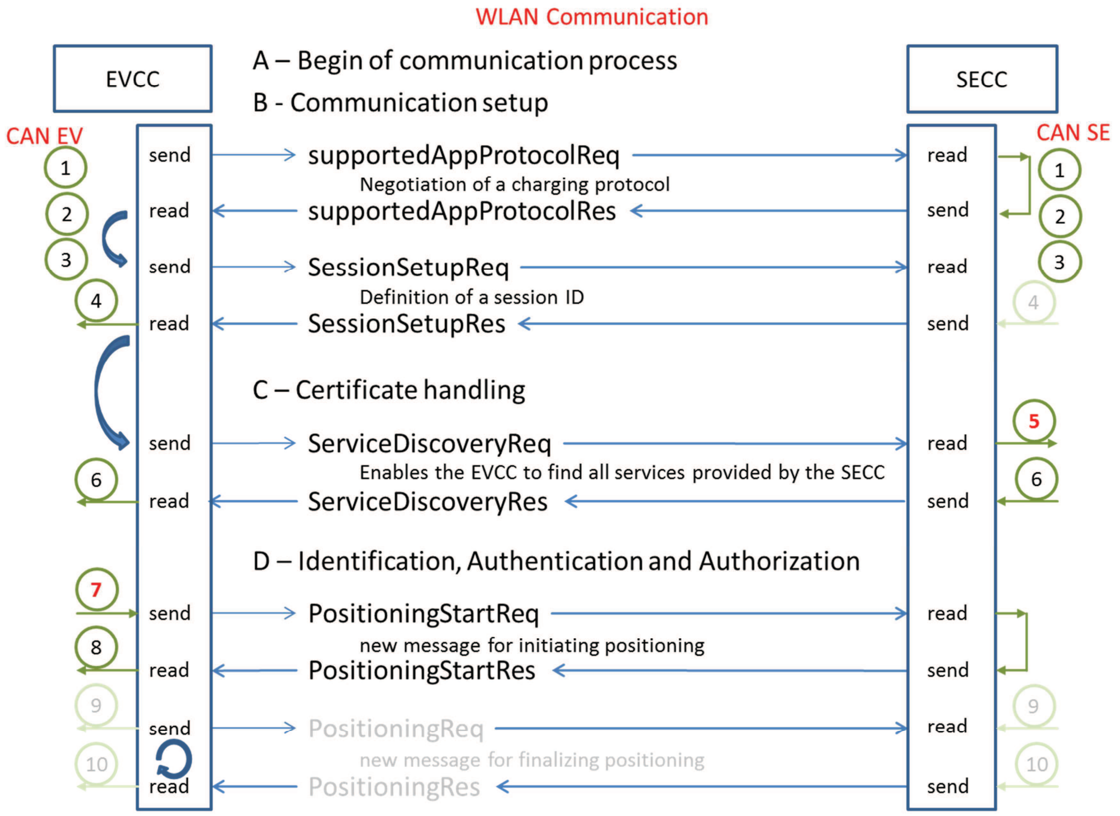


Figure 61: Proposal of the communication between EVCC and SECC - 1

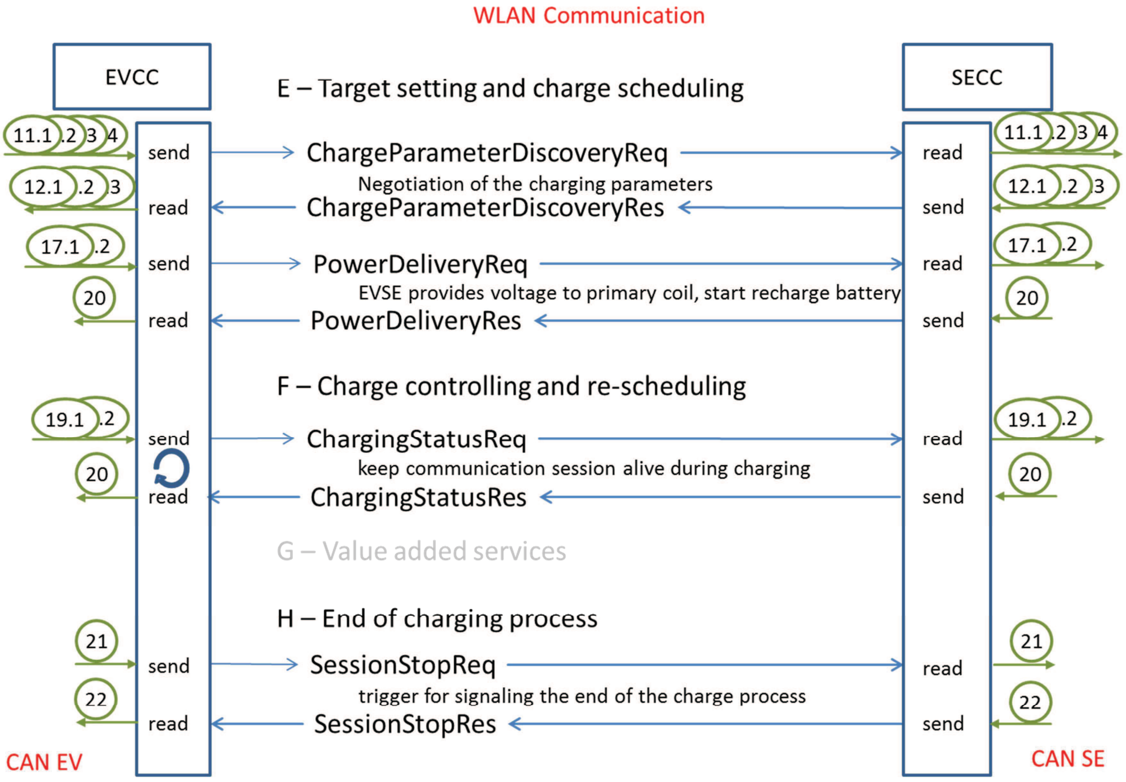


Figure 62: Proposal of the communication between EVCC and SECC - 2

Figures represent the communication process between EVCC (Electric Vehicle Communication Controller) installed on the vehicle and SECC (Supply Equipment Communication Controller) installed in the infrastructure. Steps of the communication process are numbered.

5 Feasibility analysis of coupling system: efficiency/relative position

5.1 Technical feasibility of the static en-route charging: efficiency, relative coupling

Concerning static en-route charging, there are several aspects that differ from the stationary charging process. This paragraph deals with the challenges and obstacles which result from the originally designated way of charging. The necessary communication, the efficiency, the technical limits and necessary modifications and finally some safety issues will be depicted. All considerations are based on the developed pick-up device and the Fiat Microvett test vehicle, but can also be carried over to almost any electric vehicle, which is available on the market so far.

5.1.1 Communication

Regarding communication for static en-route charging, two tasks have to be distinguished. When approaching a traffic light, which is equipped with an appropriate road inductive coil, there needs to be some kind of communication between car and infrastructure about the presence of the charging infrastructure, its position and compatibility has to be checked (frequency). Once the car and the infrastructure have authenticated each other and the compatibility check was successful, the driver needs to be informed about the possibility to charge at the upcoming traffic light. So far the communication does not require any interaction from the driver. At this point, several questions arise:

- Does the driver want to charge at all?
- Is it up to the driver to make this decision, or is the charging process fully automated?
- If the driver may decide himself, how is his desire to charge communicated to the car (for example button press each time an adequate charging infrastructure is in reach)

Since the authentication in itself and also the following positioning process will take time, this time span is not available for charging. This circumstance is dealt with later in the efficiency section of this paragraph, where the average duration of a stop light phase is regarded concerning the maximum amount of energy rechargeable.

5.1.2 Technical limitations and necessary modifications

The battery management system of the Fiat Microvett test vehicle is designed to operate in charge mode or in discharge mode. Therefore, while driving, the car is in discharge mode and does not allow any charging process except for recuperation while braking. Originally, the car is equipped with an onboard charger, which will be activated by supplying voltage to the power inlet. At the moment the car gets plugged in, the battery management switches from driving mode to charging mode, communicating the desired charging current to the onboard charger. From this point, the vehicle’s drivetrain is switched off.

In order to implement the developed pickup-device into the test vehicle, the onboard charger has to be removed and replaced by the secondary coil unit which also uses the car’s desired charging current signal to adjust the charging current. Since there is no plug anymore, which can be plugged in to put the battery management system into charging mode, this process has to be simulated. Simulating the plugging in of the connector also brings along some safety issues, which are dealt with in the safety section of this paragraph. The problem of not having a dedicated charge mode, where the drivetrain is switched off and a discharge mode, where no charging is allowed can be solved by implementing an energy manager (Figure 63).

Figure 63: Schematic of energy manager

5.1.3 Efficiency

Having a closer look on the efficiency of the static en-route charging process, it is interesting to calculate the amount of energy, which is recharged while waiting in front of the stop light. This can be done by assuming an average waiting time and subtracting the time for authentication and positioning. The remaining time can be seen as pure charging time. Since there was no reliable literature about the average waiting time in front of traffic lights and the time for finding the charging position, this way of calculating is not very precise to make a statement concerning efficiency.

Therefore, from this point the pure charging time is considered. The amount of energy, which can be recharged depends on charging time and the energy transmittable which is dependent on the coupling factor and overall efficiency. Considering the developed 3.7kW charging system, Figure 64 shows the energy rechargeable regarding different cases.

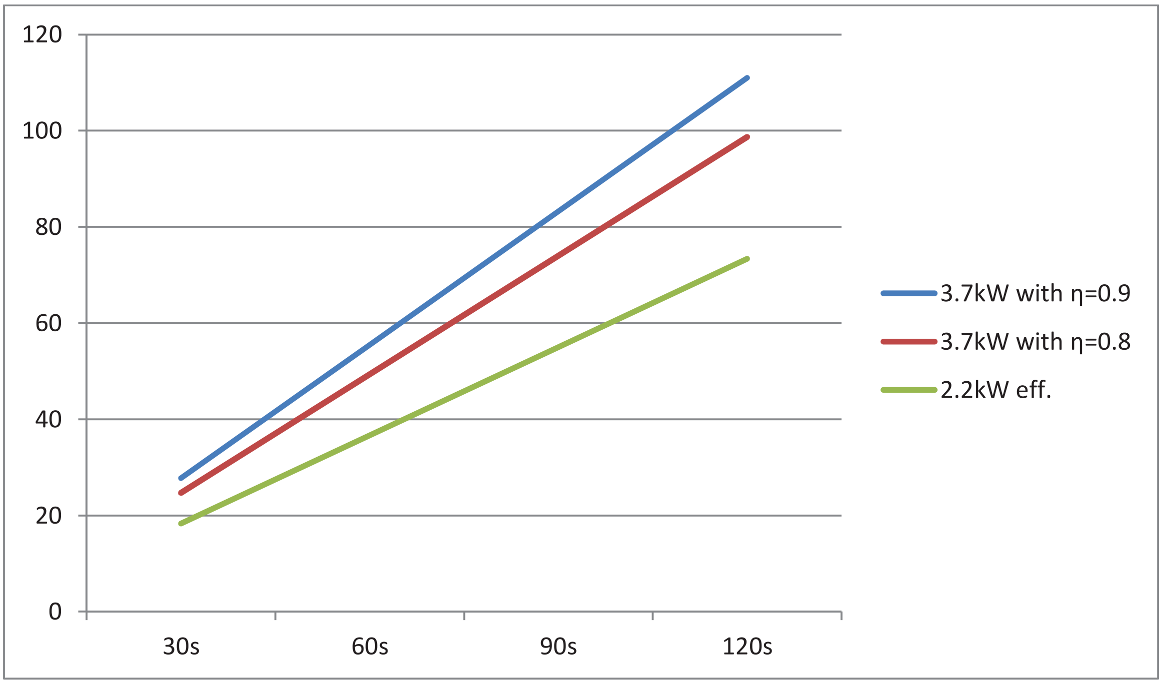


Figure 64: Energy rechargeable (Wh) depending on charging time

Since the test vehicle’s battery system is limited to be charged with a maximum of 10A, the coil and the charging system have been limited to 2.2kW. Based on this limitation, the Fiat Microvett is able to recharge between 18.33Wh and 73.33Wh considering a charging time of 30s to 120s. Without the limitation of the test vehicle’s battery system, values between 27.75Wh and 111Wh (η=0.9) and between 24.67Wh and 98.67Wh (η=0.8) are possible.

In order to have a better understanding of what effect this amount of recharged energy has on the overall cruising range, the vehicle’s battery capacity and the average energy consumption have to be measured.

The measurements stated a battery capacity of 22kWh and an average energy consumption of 13.98kWh/100km. Since the battery can never be fully discharged, an effective range of 139km results. Figure 65 shows the amount of energy recharged in relation to the battery capacity for the developed pickup device in combination with the test vehicle for a different count of stops. To complete the considerations, Figure 66 and Figure 67 show the same information based on 3.7kW charging power with an efficiency of η=0.8 and η=0.9.

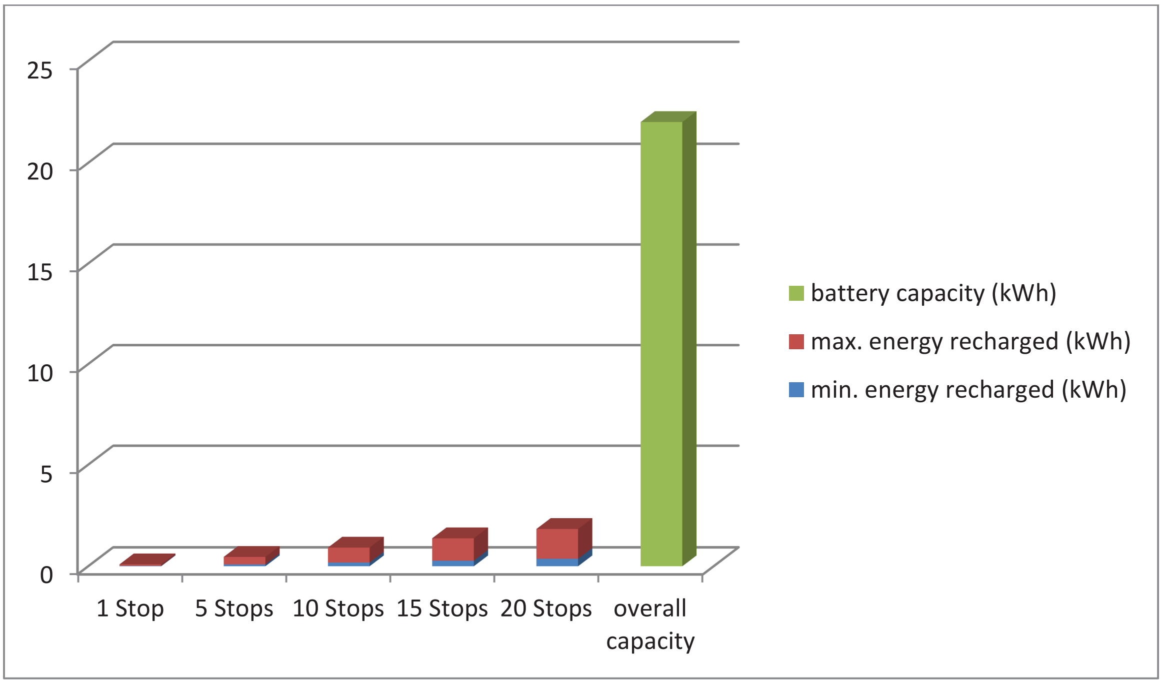


Figure 65: Min./Max.energy recharged at 2.2kW

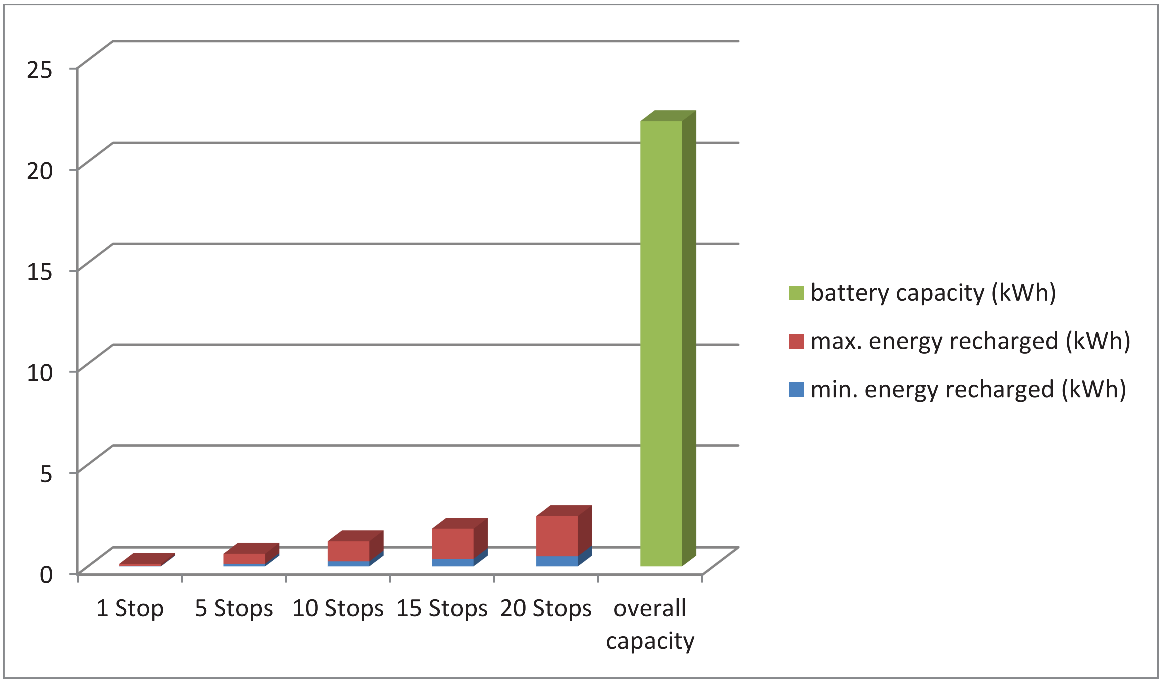


Figure 66: Min./Max. energy recharged at 3.7kW with η=0.8

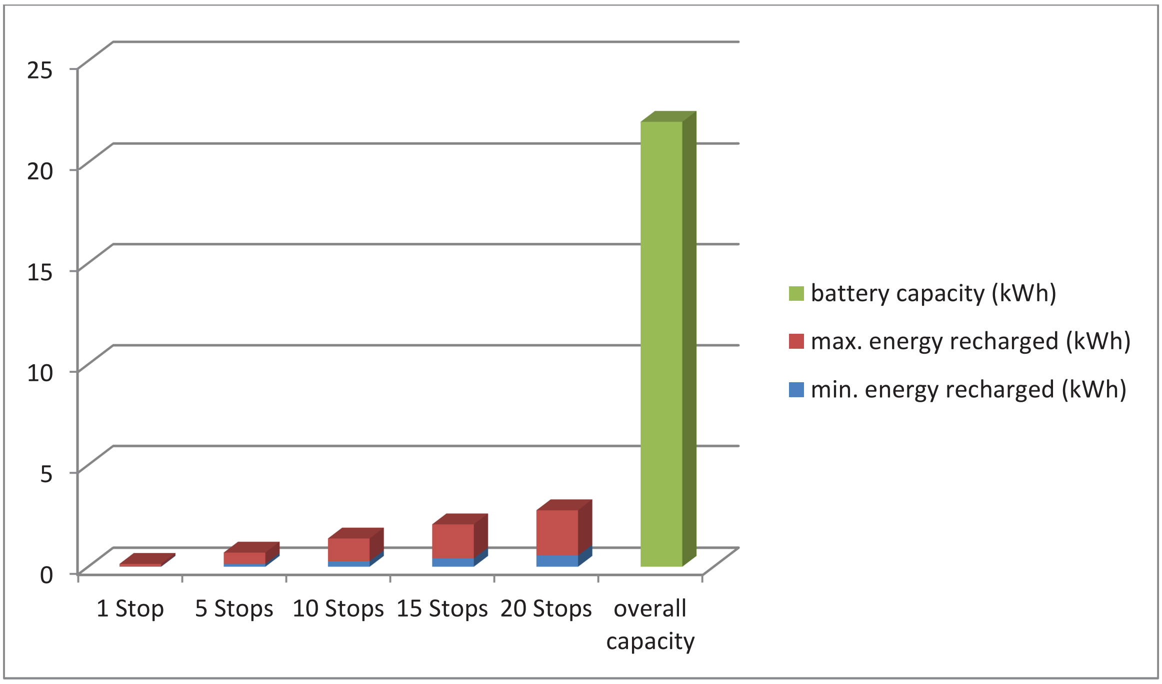


Figure 67: Min./Max. energy recharged at 3.7kW with η=0.9

Bringing together the information about the average energy consumption and the possible scenarios of recharging, for each case the gain of range can be expressed. Figure 68, Figure 69 and Figure 70 show the minimum and maximum range gain for each scenario.

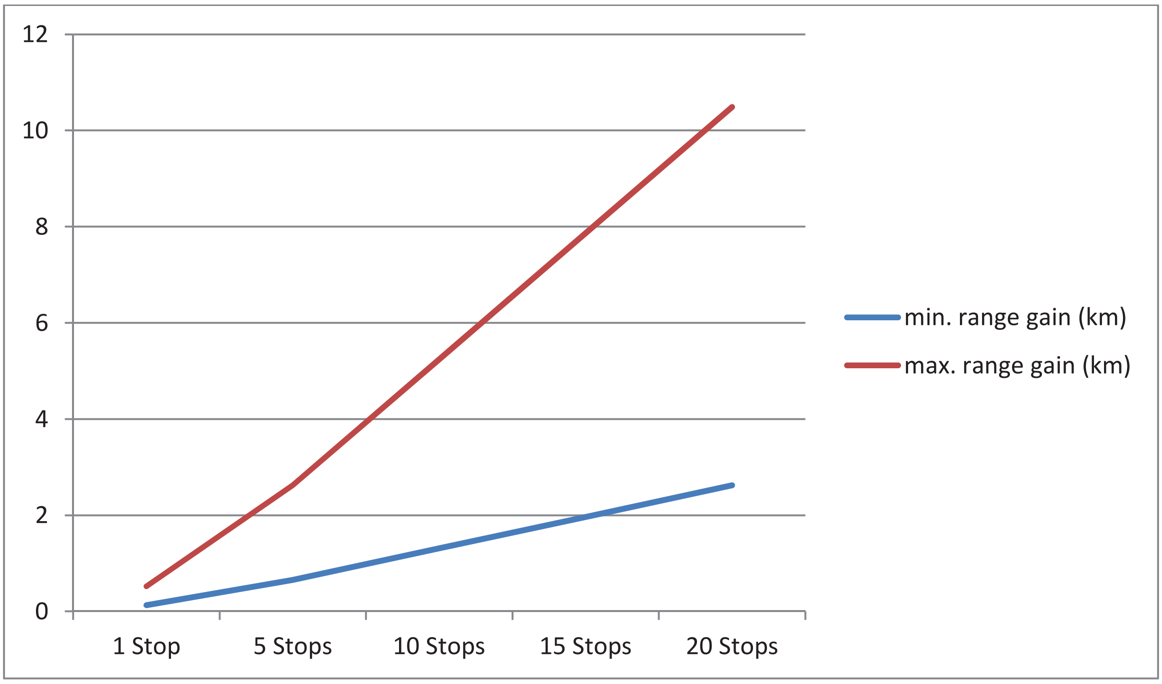


Figure 68: Min./Max. range gain at 2.2kW

Regarding the build-up pick up device and the test vehicle's limitation to 2.2kW charging power, the blue line (Figure 68) depicts that a single stop for 30s results in a range gain of 130m and a single stop for 120s results in a range gain of 520m (red line). The assumption, that the charging process is somewhere in between 30s and 120s leads to the conclusion, that the overall energy recharged after 20 stops is between the red and the blue line. Therefore the range gain is about 2.62km to 10.48km after 20 stops.

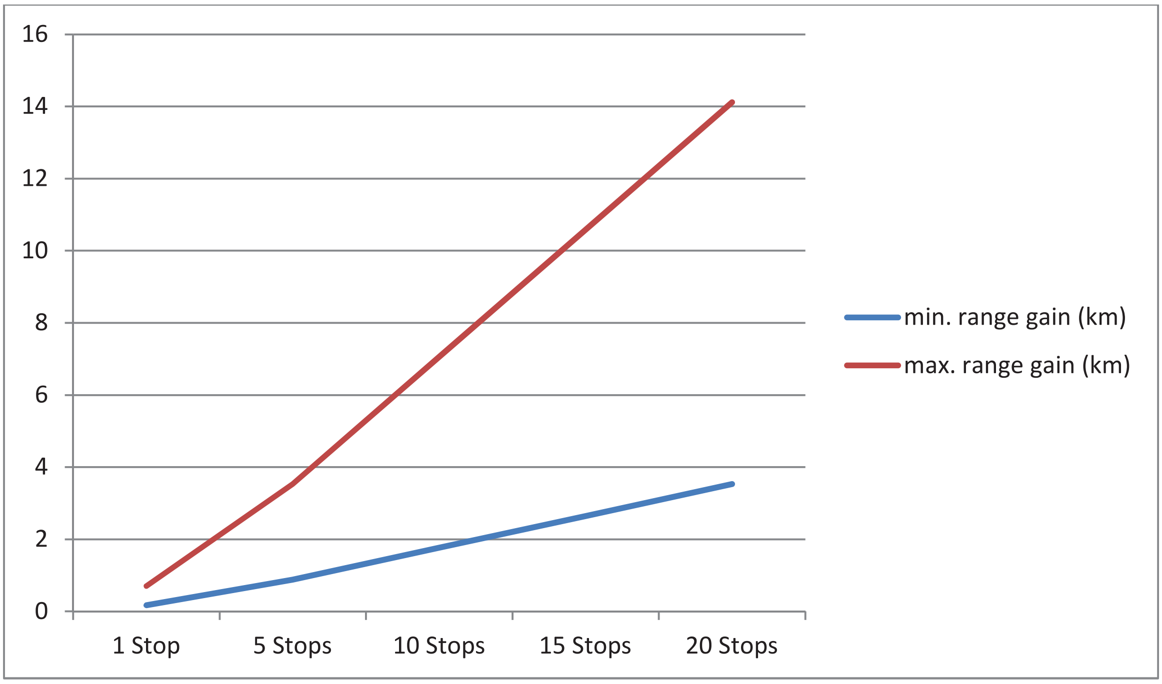


Figure 69: Min./Max. range gain at 3.7kW with η=0.8

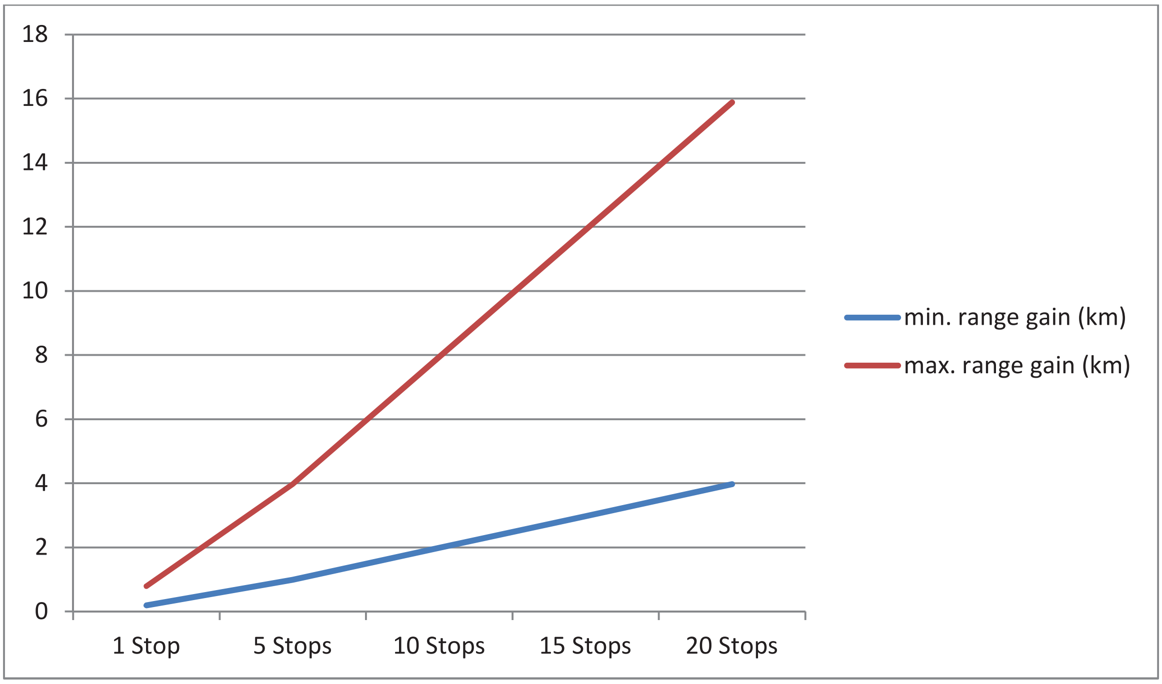


Figure 70: Min./Max. range gain at 3.7kW with η=0.9

Without the limitations of the vehicle's battery system, the developed pickup device is able to achieve a range gain of 200m in 30s and 790m in 120s with a single stop, assuming an efficiency of η=0.9. This leads to an overall range gain between 3.97km and 15.88km after 20 stops.

Table 11 summarizes the above presented data.

	Energy recharged after 1 stop (Wh)				Energy re-charged after 20 stops (kWh)		% battery ca-pacity re-charged after 20 stops		Range gained (km) after 20 stops	
	30s	60s	90s	120s	Min	Max	Min	Max	Min	Max
2.2kW	18,33	36,67	55	73,34	0,367	1,468	1,67	6,67	2,62	10,48

3.7kW@ η=0.8	24,67	49,33	74	98,67	0,493	1,973	2,24	8,97	3,53	14,12
3.7kW@ η=0.9	27,75	55,5	83,25	111	0,555	2,22	2,52	10,1	3,97	15,88

Table 11: Overview of the different charging scenarios

Based on this data, the suitability of the developed charging system for different driving scenarios can be examined and rated.

- Urban
    - Short distance
    - Many traffic lights (many stops)
    - Longer traffic light phase (more traffic, pedestrians)
- Highway/Country road
    - Long Distance
    - Less traffic lights (few stops)
    - Shorter traffic light phase

It is obvious, that the developed system is only suitable for urban driving, since frequent stops and recharging phases are necessary to recharge a considerable amount of energy. Driving short distances in combination with frequent charging phases are optimal for static en-route charging with the developed pickup-device. In contrast, long distance travelling with few traffic lights and therefore few charging stops has almost no effect on the overall range available.

To further increase the energy recharged, the only possibility is increasing the charging power.

5.1.4 Positioning

In comparison to charging in the parking lot, where the driver has the opportunity to reposition in case of a transversal offset of primary and secondary coil, there is only one attempt to find the correct charging position regarding static en-route charging. The developed positioning system, which makes a rough position estimation using camera based techniques and uses RFID tags for the fine positioning, is based on determining the actual position and hence calculating the trajectory and displaying this information to the driver in order to make adjustments. This only works at very low speeds (for example in parking maneuvers) and is not applicable for static en-route charging. Here a different approach has to be found. Because of the higher speed when approaching a traffic light, the information has to be provided earlier to the driver, maybe using the lane keeping assistance. For fine positioning, the use of another method is necessary.

5.1.5 Safety

As mentioned in the technical limitations section, the car has two dedicated modes: discharge mode and charge mode. While in discharge mode, the battery system is not able to recharge via the onboard charger or via the developed inductive charging system. This means, in order to recharge the battery, the vehicle has to be brought into charge mode, which means that the drivetrain is switched off for safety issues. This results from the fact that the car isn't allowed to move, while it is charged respectively plugged in. Since the Fiat Microvett is the basis for implementing the inductive charging system, the only way of bringing the vehicle into charge mode is to simulate the plugging in of the power connector of the conductive onboard charging system. This simulation of the power plug is a safety issue, because a failure in simulation, maybe while driving will result in inhibiting wheels, which is an unsafe condition.

While inductively charging, the car has to be prevented from moving. In case of moving, while the primary coil is still powered up, car parts other than the secondary coil could be heated up and damaged. Therefore, there must be some kind of detection possibility in order to shut down the primary coil when the vehicle starts moving, respectively when the driver wants to leave the traffic light, because lights have changed.

A solution is an energy manager which has to be implemented additionally into the battery management system. This way, energy transfer to the battery is possible even when the car is in discharge mode. By measuring the power transmitted and by monitoring the charging current, the energy manager can also detect the movement of the car, because moving results in a transversal offset, which has an effect on the coupling factor and therefore on the power transmittable respectively the current (Figure 63**¡Error! No se encuentra el origen de la referencia.**).

5.2 Parking accuracy analysis for stationary and static en route charging

One of the main issues concerning the static en-route charging is to determine how easily a driver is able to stop the vehicle on the target, in order to allow the recharging system work efficiently. To investigate the driver skill, the UNIFI study team organized and performed two kinds of tests:

- The stationary charging
- The static en-route charging, while the driver stops the vehicle at a traffic light

both cases the aim of the tests wasn't to check the efficiency of some specific visual or audio aids, but to verify if and how the sensorial aids potentially help the driver to reach the targets. Following this idea the used aids should be simply treated as archetypes.

The stationary charging test allowed us to verify the driver's skill while parking a four wheeled vehicles along the street. To do it, a vehicle mounted with a parking video monitoring system was used to verify how an already available on market technology can help the driver to perform the maneuver in repeatable way. During the maneuver, the drivers used only some ground painted lines as a target reference.

Once the stationary coupling tests were analyzed, the static en-route charging tests were performed using the vehicle stopping at a traffic light as a reference condition. The tests analyze three different conditions:

- **Non aided stop**: the driver knows that he has to stop the vehicle on the target but he cannot use any visual or audio aid to do it
- **Visual system aided stop**: the driver can use some visual aids to stop the vehicle
- **Audio/visual system aided stop**: the driver can use some visual and audio aids to stop the vehicle

In order to obtain the reproducibility and the repeatability of the tests:

- the parking place along the street and the traffic light stop were reproduced in a restricted zone inside the parking area of the University of Florence, in order to avoid external factors (traffic conditions, such as other vehicle's influence on the driver's behavior) that could have affected the test and the measurements;
- in both cases, all the test were performed within one hour, in order to have the same visibility conditions (in both cases weather conditions were good);
- the same car was used for all the tests.

5.2.1 Stationary charging test

The main objective of the test was to analyze the driver's skill while parking a four wheeled vehicle along the street. A vehicle mounting a parking monitoring system was used to verify how an already available on market technology can help the driver to perform the maneuver in repeatable way.

A Mazda CX-5 was used. The vehicle was equipped with a parking assist system that combines a rear view parking camera and front/rear parking sensors. Using this technology the driver could verify on a 5.8" display the car's actual position with respect to any rear obstacle (such as other parked cars, etc.). The rear camera position (Figure 71) and its angle view allows the driver to see objects on a wide area (Figure 72).

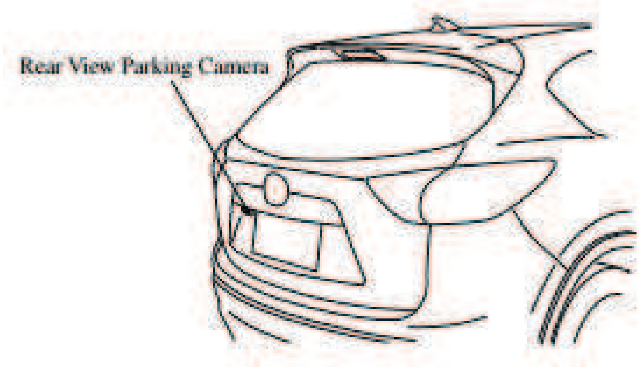


Figure 71: Rear view parking camera position (from Mazda CX-5 owner's manual)

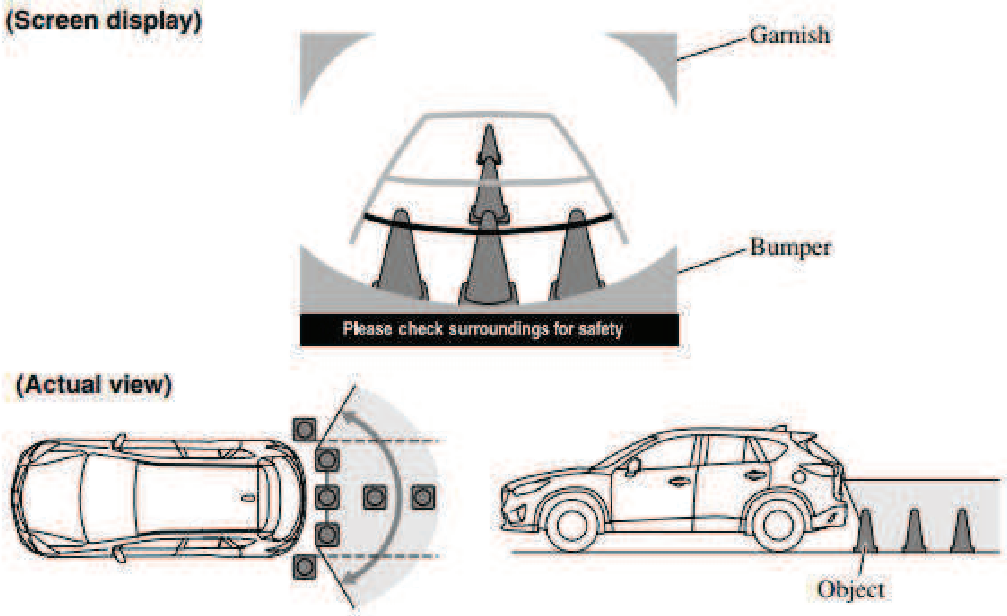


Figure 72: Actual view and screen display (from Mazda CX-5 owner's manual)

Assuming that the drivers can easily improve their skill with each parking repetition, it was decided to ask the participants to repeat the maneuver many times. Later, the drivers were chosen such that they had no previous experience with the audio/visual combined parking assist system. In order to carry out a sufficient number of tests in a repeatable way, 5 drivers (3 men and 2 women) had been asked to repeat 5 times the same test. Drivers used only some painted lines as a target reference, with no extra infrastructures. The parking target of the car was defined by means of lines placed on the street (in white in Figure 73) that suggested the drivers both the longitudinal and transversal position. In particular, the rear position was defined by means of 4 parallel lines (in white in Figure 74).

Figure 73: Parking target of the vehicle (frontal view)

Figure 74: Parking target of the vehicle (rear view)

The test drivers were informed about the purpose of the research but they were not trained about the use of the parking assist system. They were only asked to park as precisely as possible inside the target position.

To measure the actual transversal and the longitudinal position of the vehicle with respect to the target position (in white in Figure 75) at the end of each parking maneuver, some frontal and lateral marker (in green in Figure 75) were applied on the vehicle and on the street.

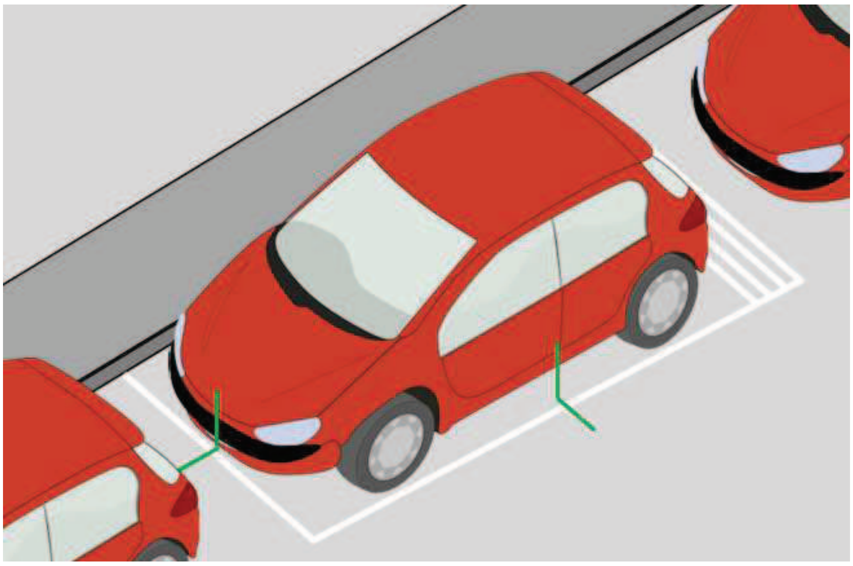


Figure 75: Distance from target measuring system

While parking, the rear view parking camera displays the painted target lines (in white in Figure 76), superimposed on the reference guide lines, automatically shown by the vehicle display (in yellow in Figure 76), that approximately defines the width of the vehicle. To reach the target, the driver had to align the reference guide lines with the ground painted ones.

Figure 76: Actual display image while in target position

25 repetitions of the maneuver were carried out. As mentioned earler the drivers weren't experienced with the use of audio/visual parking assist system, therefore they had to learn to use it while performing the maneuver. Considering all the repetitions, the mean longitudinal and transversal differences from the target position are 2.4 cm and 5.6 cm respectively but, as expected, starting from the first test, each driver improved their skill and the final results were much better than the first ones. Results are shown in Figure 77 where, for each test, the mean longitudinal and transversal differences from the target are shown. The mean longitudinal difference starts from a mean of 9.8 cm and reach a final mean value of 1.2 cm, while the transversal one passed from 4.0 cm to 0.4 cm.

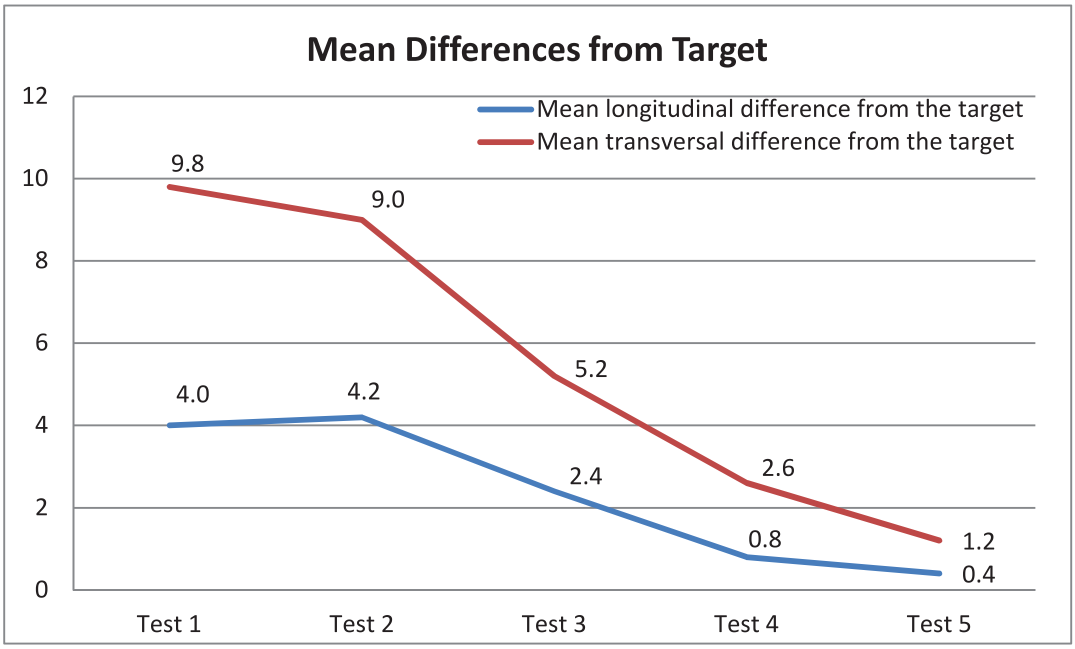


Figure 77: Mean differences from target for each test

5.2.2 Static en-route charging test

The main objective of the test was to analyze the driver skill while stopping a four wheeled vehicle at a traffic light. As written, the aim is to perform a driver behavior comparative study under different conditions:

- **Non aided stop**: the driver knows that he has to stop a vehicle on the target but he cannot use any visual or audio aid to do it
- **Visual system aided stop**: the driver can use some visual aids to stop the vehicle
- **Audio/visual system aided stop**: the driver can use some visual and audio aids to stop the vehicle

In order to carry out a sufficient number of tests in a repeatable way, a traffic junction with a traffic light was reproduced in a closed test area and 13 drivers were asked to take the test. A histogram of the driver's age is shown in Figure 78. 10 men and 3 women performed the test.

Figure 78: Age of drivers

A Peugeot 206 was used. A frontal and a lateral marker (in green in Figure 79) had been placed on the vehicle in order to measure the vehicle's actual transversal and the longitudinal position with respect to the target position (in black in Figure 80) at the end of each test.

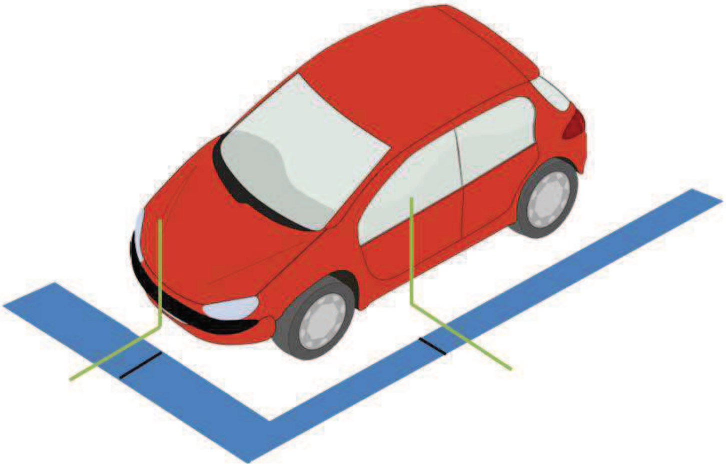


Figure 79: Distance from target measuring system

The divers had to repeat 4 times the non-aided maneuver and 3 times each the two aided maneuvers. Before each test the drivers were informed about the purpose of the research and they were suggested to behave as they were to stop at a normal traffic light stop signal.

Non aided stop
During the non-aided maneuver the drivers were asked to stop the vehicle at the center of the driving lane using only the painted lines as a reference. The longitudinal position was assumed to be in target if the front bumper was in line with the internal edge of the transversal line (Figure 80). No other aids were mounted or used during those tests in order not to give drivers any help.

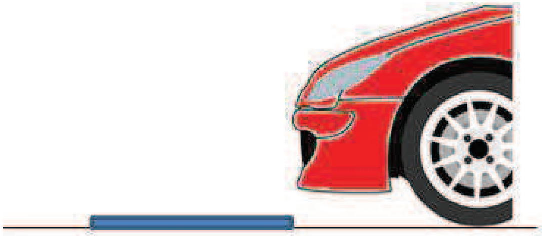


Figure 80: Target position for not aided stop

Visual system aided stop
During the visual aided maneuver the drivers were asked to stop the vehicle at the center of the driving lane using as reference the painted lines and a pole placed on the right side of the street. The longitudinal position was assumed to be in target if the right rearview mirror was in line with the pole (Figure 81).

Figure 81: Target position for visual system aided stop

Audio/visual system aided stop:
During the electronic audio/visual system aided maneuver the drivers were asked to stop the vehicle at the center of the driving lane using as reference the painted lines and a parking sensor mounted on the front bumper. The longitudinal position was assumed to be in target if the parking sensor display showed a distance of 0.5 meters from a target placed on the street (Figure 82)

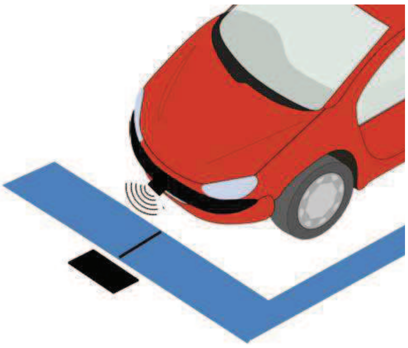


Figure 82: Target position for audio/visual system aided stop

53 non aided stop maneuver repetitions were done. The scatterplot of results is shown in Figure 83. Each red dot shows the distance from the target, that is (0,0).

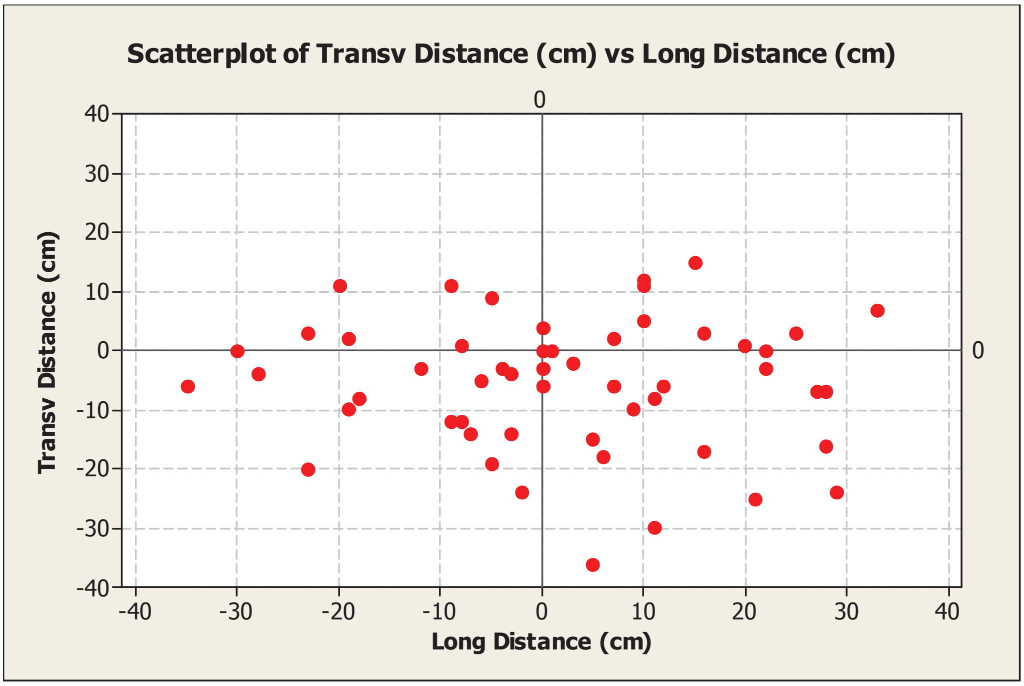


Figure 83: Scatterplot of transversal distance vs. longitudinal distance for not aided stop

39 visual system aided stop maneuver repetitions were done. The scatterplot of results is shown in Figure 84. Each red dot shows the distance from the target, that is (0,0).

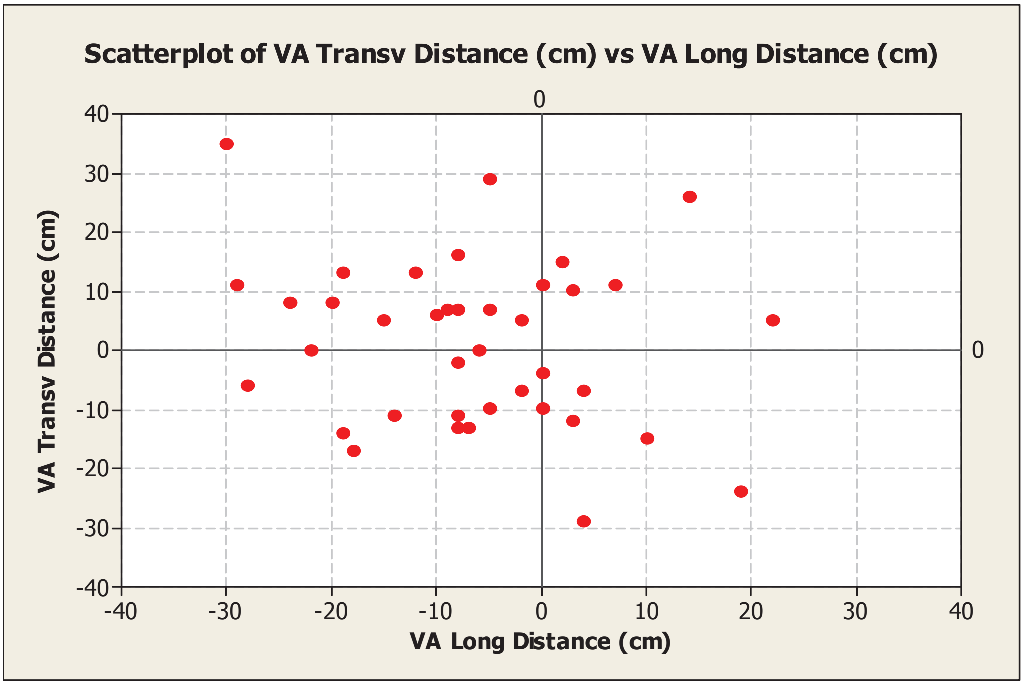


Figure 84: Scatterplot of transversal distance vs. longitudinal distance for visual system aided stop

39 audio/visual system aided stop maneuver repetitions were done. The scatterplot of results is shown in Figure 85. Each red dot shows the distance from the target, that is (0,0).

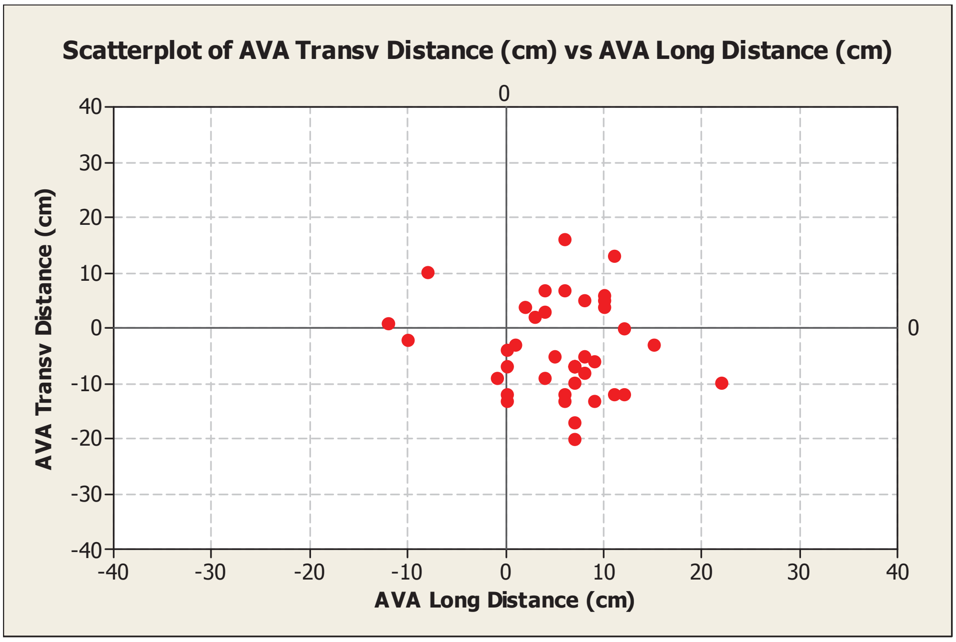


Figure 85: Scatterplot of transversal distance vs. longitudinal distance for audio/visual system aided stop

The scatterplot of all maneuvers results is shown in Figure 86. Each black dot shows the distance from the target for the non-aided solution, each red dot shows the distance from the target for the visual aided solution and each green dot shows the distance from the target for the audio/visual aided solution. The target, as before, is (0,0).

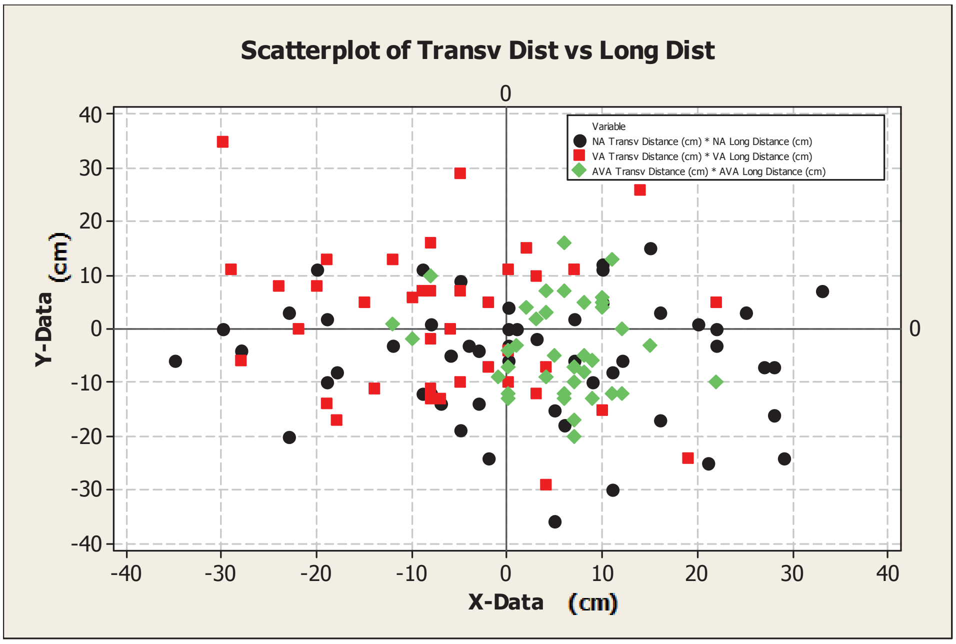


Figure 86: Scatterplot of transversal distance vs. longitudinal distance

The overall results for transversal skill are shown in Figure 87. The audio/visual system aided stop shows lower mean and standard deviation, due to the fact that the target placed on the street helped the driver to find a more in target transversal position.

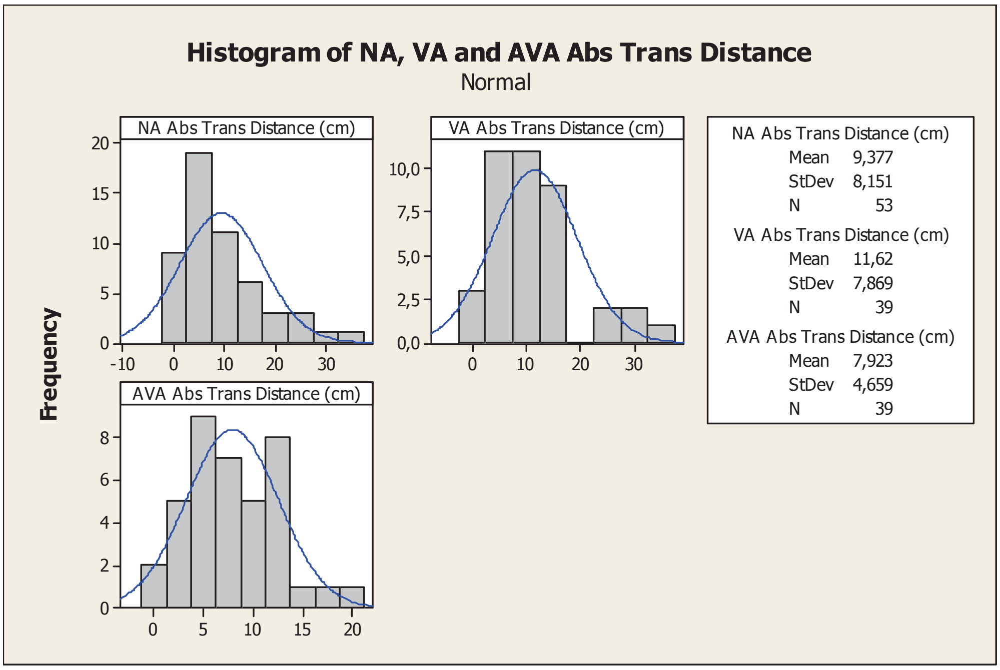


Figure 87: Histogram of transversal distance

The overall results for longitudinal skill are shown in Figure 88. As expected, the audio/visual system aided stop shows lower mean and standard deviation.

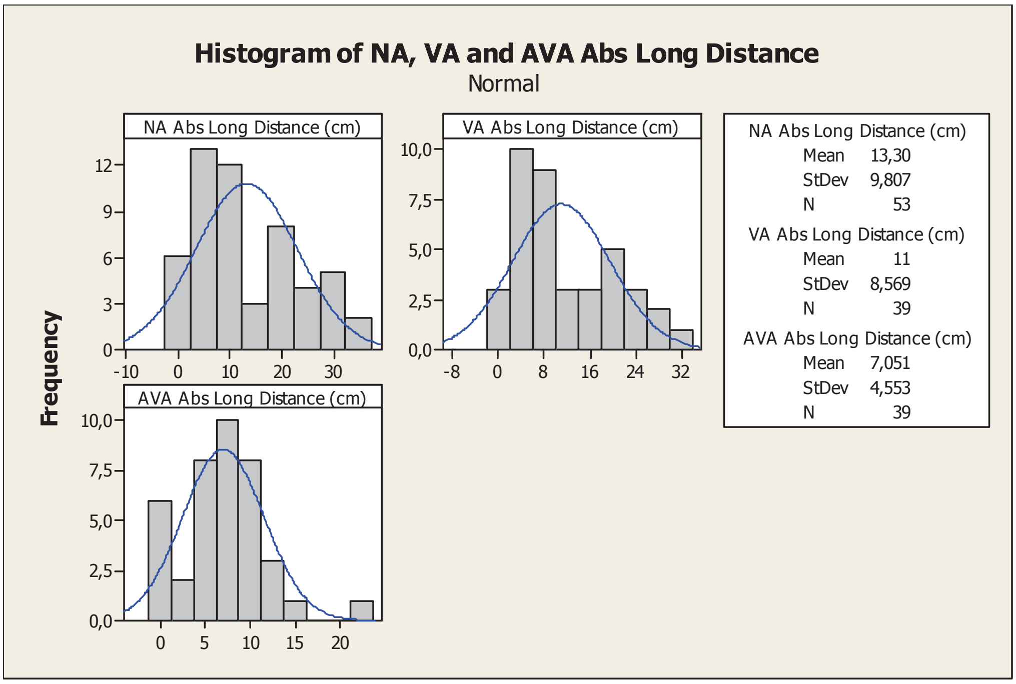


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Figure 88: Histogram of longitudinal distance

Table 12 shows the comparison between the tests.

	Test	Long distance		Trans. distance	
		Mean	St. Dev.	Mean	St. Dev.
Not aided stop	53	13.3	9,8	9.3	8.1
Visual system aided stop	39	11,0	8,6	11.6	7.9
Audio/visual system aided stop	39	7,0	4,5	7.9	4.7

Table 12: Comparison between the tests

Due to the obtained results the audio/visual system will be considered as a starting point for the development and better solutions that will be investigated in next studies.

6 Investigation on additional commercial vehicles' needs and possible synergies with other intelligent transport systems

6.1 Needs and opportunities for en-route static charging

One could argue what is the need for en-route static charging and in the end it depends of whose view you have. There are many different stakeholders, see Figure 89, that influence and are influenced by a potential en-route static charging system.

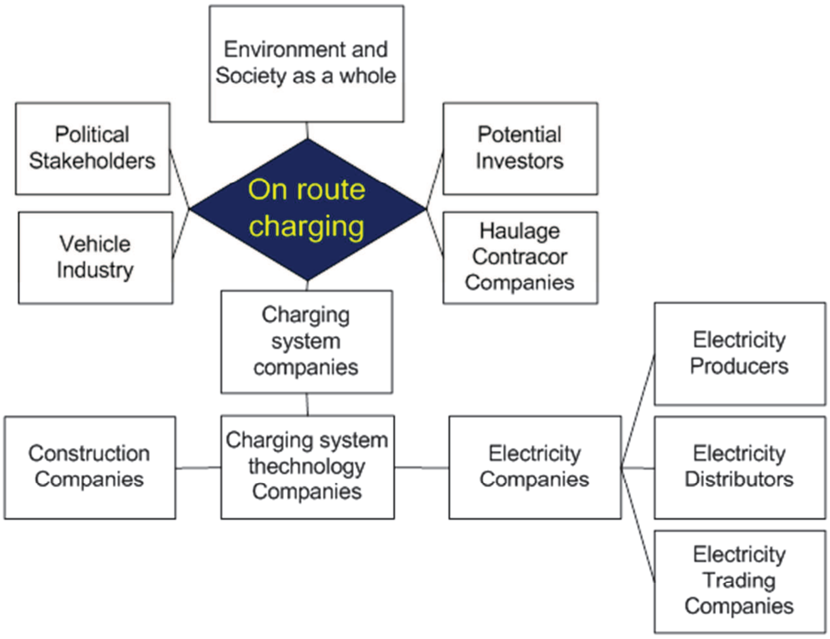


Figure 89: Influence potential of en-route static charging system on Stakeholders

In this task the focus are on commercial vehicles and since the DOW specify a truck, in the next chapter the question of the needs and opportunities, en-route static charging has to offer a commercial freight transport company will be asked.

Freight companies are part of a low-margin and high-investment industry that is extremely competitive. There is little or no room for investments that do not generate profit (preferably directly). In spite of this, there are frequent demands for the use of alternative fuels and energy carriers. These demands come from customers as well as from society as a whole. The choice of fuel or energy carrier is however quite complex. There are many factors that need to be taken into consideration and the new options will be compared to the existing mature diesel-based system.

6.1.1 COMMERCIAL FREIGHT

Typically, road freight companies have a low profit margin, often around 1-2%. The largest share of the costs is staff, ranging from 35% to 55% of the total. The second largest is diesel (10-23%) and the third is depreciation, i.e. vehicle cost (10-13%). Overall, the ratio of fixed versus variable costs is high in the transport industry. Between 18-35% of the costs are considered variable (fuel, maintenance and tires), the rest are more or less fixed (staff, insurance, depreciation etc.). This means that the revenues must cover not only the running costs but also a large overhead. As a result of this, there is little room for non-revenue generating activities. In fact, a study of German transporters shows that only 1.1% of their revenue is spent on innovation.[4]

There are some intrinsic properties of the freight transport industry that are worth notifying. In Sweden, 91% of the road freight weight is transported less than 300 km and medium duty distribution trucks usually drive less than 100 km per day. The transportation industry is very fragmented, both when it comes to company size and services provided. The average number of trucks of a Swedish haulage company is 3.7, and more than 80% of the companies have five trucks or less. Moreover, the transport industry services everything from waste management to agriculture, manufacturing, trade, mining, forestry, and construction industries. These industries have little in common when it comes to the nature of the transportation service in terms of distance, vehicle type, goods type, market situation and administrative processes. The heterogeneity of the companies and of the services they provide leads to difficulties in finding solutions that will fit all needs.[5]

The freight industry acts as an intermediary in supply chains. There are a large number of stakeholders involved, including consignor, consignee, transport buyer, transport company, hauler, driver, governments, municipalities and private citizens, that have demands concerning reliability, security, safety and sustainability. The transport system is not allowed to break down, be delayed or otherwise impeded. Measurements such as uptime, delivery precision and service level are used to ensure reliability. Since the 9/11 attacks, there are also stringent regulations in place guarding against terrorist threats. There is an increasing focus on crime-related security issues. The Swedish government has famously proclaimed that no people should be seriously harmed or killed in traffic related accidents (also called the Vision Zero). Companies, both sellers and buyers of transport services, are now working systematically with transport safety issues. Regarding sustainability demands, both public opinion as well as EU-wide regulations, are forcing the transportation industry towards alternative energy as well as higher energy efficiency. [6]

In order to evaluate en-route static charging, all aspects above must be considered. Moreover, the evaluation will likely differ between stakeholders.

6.1.2 Needs for en-route static charging

Many experts believe that the future is going to be dominated by hybrid vehicles: vehicles using electricity in combination with biofuels. This would create a change regarding what kind of vehicles are used. For passenger cars, a battery and/or a fuel cell is enough to power the electrical motor in most cases. With an improved future battery capacity, the concept is that these will be charged during night time and used for distances up to 100-150 km the day after. For longer trips, the ICE (preferably using biofuels) is available for a longer distance reach. For heavy vehicles, such as trucks and buses, the battery capacity will however not be enough.[7]

The heavier the vehicle is, the heavier the battery. This makes the vehicle even heavier, which in turn requires the battery to be even larger. This becomes an unsolvable circle. Hence, if not something extremely drastic happens to the battery development, using batteries as the power source in heavy vehicles will not be enough unless the hassle of charging and the driving distance between the charging points could be kept to a minimum.

Charging challenge regardless of battery size

Time to charge 100 km	Battery for 100 km
2 minutes	60 kg diesel-tank
3 days	2400 kg battery
4 hours	2400 kg battery
1 hour	2400 kg battery

Figure 90: Charging challenge regardless of battery size

It is not realistic to let equipment, consuming 30 to 150 kW of average power to be pure electric and run on batteries as long as charging occasions are few! As an example with a medium duty distribution truck using on average 50kW of power you would need:

50 kW x 10 h = 500 kWh => more than **5 tons of today's batteries!**

This is for 10 hours of use and one charging occasion between uses.

Even if some disruptive battery technology could be found charging would still be a challenge, see Figure 90 for comparison. Charging the battery will take ages, even with very high charging power, compared to filling up the diesel tank.

In conclusion, both battery size and charging time needs to be decreased!

6.1.3 En-route static charging, the first step

There is a great opportunity with en-route charging that can create a more realistic scenario. The key here is the capability for frequent charging, see Figure 91. When charging e.g. 24 times a day for 0.1 h @ 100 kW you only need:

100 kW x 0.2 h = 20 kWh = **300 to 400 kg batteries!**

And this is with the same energy use as in the example above 25x20 kWh = 500 kWh

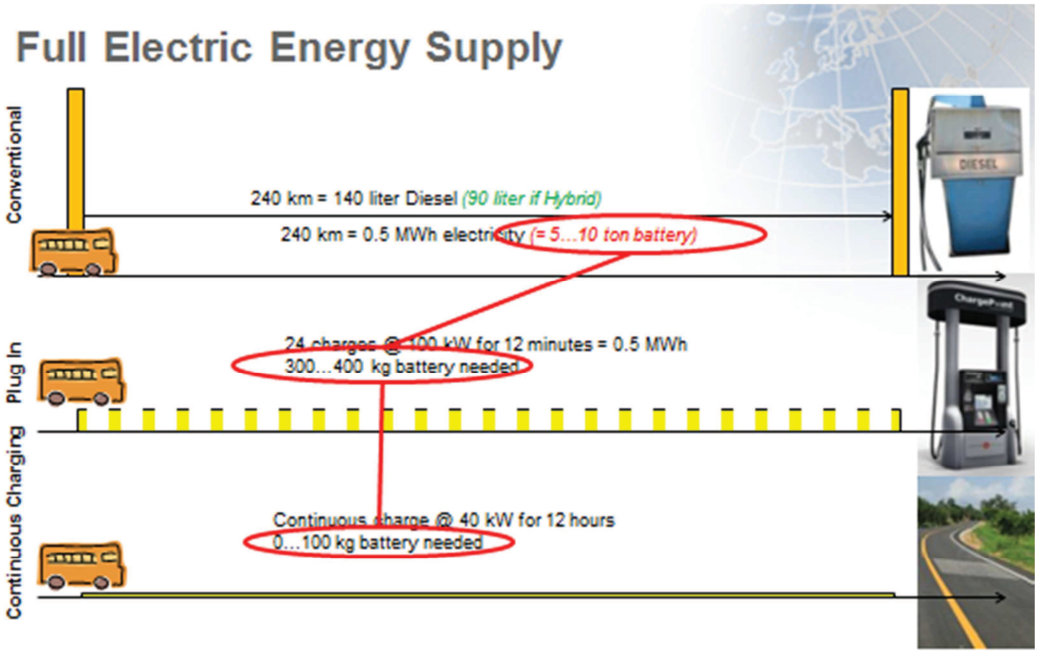
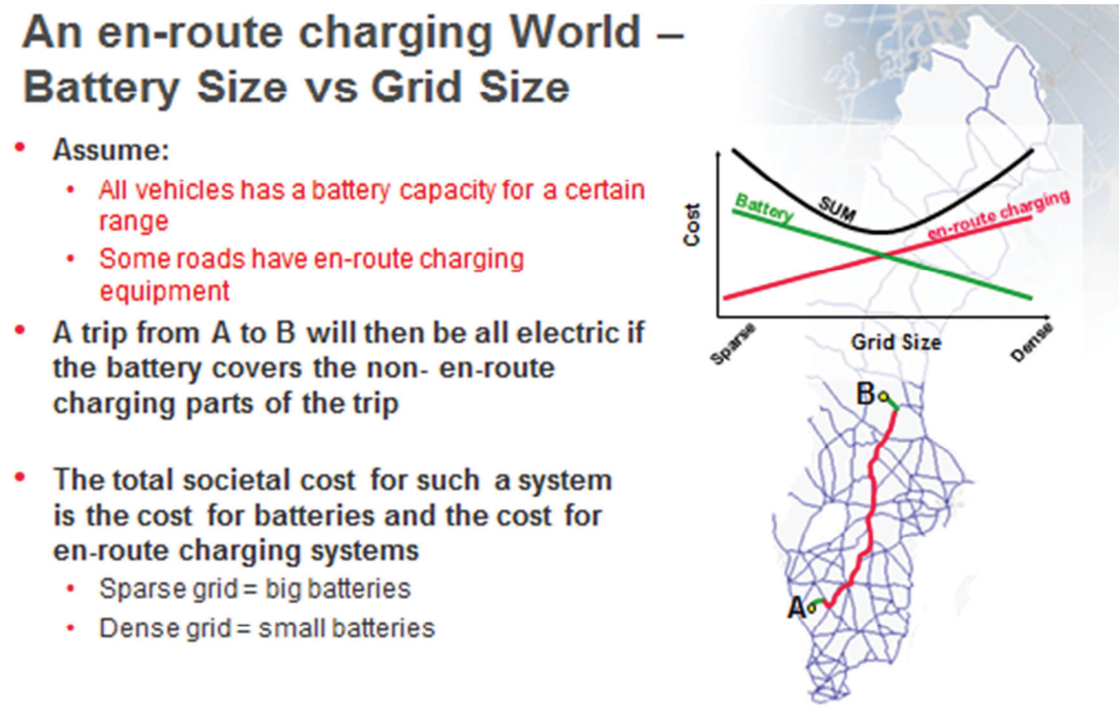


Figure 91: Frequent charging is the key

In the example above we charge every 10 km and in many urban bus applications this could be at an end station i.e. you would only need one charger for this route and in many cases the same charger could also be shared with other routes starting/stopping at the same station making it a sustainable and good business case. However stopping for 12 minutes 24 times a day does not make good use of the investment in buses and if the driver needs to wait as well the efficiency will be even worse. One way to solve this is to increase the power to 250 kW. Then only five minutes are needed to charge 0,5 kWh and this a more reasonable stop at an end station and will also be a natural break for the driver. This will then be regarded as en-route static charging since unplugged has defined maximum five minutes of charging with a stopped vehicle as en-route static charging.

6.1.4 En-route dynamic charging, best choice from a battery cost perspective

From a vehicle perspective it would be best with continues supply of power, defined as en-route dynamic charging, as in the lower part of Figure 91 because you will need less batteries (only needed for peak power) and do not have to stop (ever) for charging, but it is also driving higher infrastructure cost. Hence there is a tradeoff between battery size and frequency of charging i.e. the grid size, see Figure 92. The total societal cost for such a system is the cost for batteries and the cost for the en-route charging systems. It is easy to grasp that with a sparse grid we need bigger batteries and with a dense grid we can have smaller batteries.



An en-route charging World – Battery Size vs Grid Size

- Assume:
  - All vehicles has a battery capacity for a certain range
  - Some roads have en-route charging equipment
- A trip from A to B will then be all electric if the battery covers the non- en-route charging parts of the trip
- The total societal cost for such a system is the cost for batteries and the cost for en-route charging systems
  - Sparse grid = big batteries
  - Dense grid = small batteries

Figure 92: Battery size vs Grid size

One of the biggest challenges is interoperability i.e. to find en-route charging solutions that could serve both light and heavy duty vehicles. Another challenge is to find the first “killer applications” that can convince people, companies and governments to start the paradigm shift needed. In this task we are focusing on static charging as in the middle part of Figure 91 and as long as we focus on static charging it seem reasonable that busses or waste trucks could be the answer since they have a predefined route with regular stops. However busses generally use more fuel/energy per year and would therefore be a better business case unless there are other drivers like restricted operating hours for waste trucks with combustion engines.

6.2 Synergies possible with other intelligent transport solutions

A survey of current ITS research has been done and some of the reports found were studied in detail to be able to find synergies with en-route static charging scenarios. The suggested synergies are briefly described and before implementation one would need to define detailed scenarios and use cases.

6.2.1 Related ITS projects

The following projects have been studied to be able to find synergies with en-route static charging.

- ecoFEV (Efficient Cooperative infrastructure for Fully Electric Vehicles)
- Mobility2.0 (Develops and test an in-vehicle commuting assistant for FEV mobility)
- eMI³ (EV market join forces to harmonize the ICT data)
- mobincity (ICT for fully electric vehicles).
- Instant Mobility (exploring concept for mobility through advanced Internet technologies)

See the chapter 6.2.1.1 to 6.2.1.5 for more information about the studied projects and 6.2.2.1 to 6.2.2.6 for suggested synergies.

6.2.1.1 ecoFEV

EcoFEV (Efficient Cooperative infrastructure for Fully Electric Vehicles) is a FP7-Project ICT-2012-GC for Safety and Energy Efficiency in Mobility. Overall budget is €4.3 million and the project is co-funded by the European Union. EcoFEV will study, define and implement efficient and cooperative electric mobility system architecture for FEVs. ECo-FEV started on September the 1st 2012 and will last for 33 months.

One of the key points in eCo-FEV is to accurately calculate the range of an EV taking advantage also of information on road topology, weather conditions and traffic beside driver's behavior (e.g. acceleration and braking phases), either in real-time or based on predictions. An improved energy provision for FEVs could be provided by the use of reliable wireless communications, supporting different charging modes.

6.2.1.2 Instant Mobility

The Instant Mobility project is part of the FI-PPP initiative, co-funded by the European Commission 7th Framework. With a budget of 8 M€ and EC funding of 5 M€ the project started April 2011 and ended April 2013. The Instant Mobility project is developing and exploring a concept for transforming the mobility of persons and goods in the future through application of advanced Internet technologies. In this project several scenarios are defined and one of them is "Trucks and the city". In short the scenario starts from goods pick-up at an intermodal hub at the city perimeter or within the city with the aim of delivery at another hub or at the receiver. This scenario shows how Internet-based services can manage commercial vehicle deliveries and routing, organize drivers' shifts and synchronize vehicle movements and goods pickup and reception. In this scenario all actors, e.g. vehicle, driver, load carrier, goods, infrastructure and back-end systems, involved in commercial transport are connected to and through the future Internet.

- The expected benefits are reduced congestion, noise and air pollution as well as increased mobility of cargo flows within the urban zones.
- The increased transport efficiency will improve competitiveness and profitability of service users (cargo owners, transporters, 3PL, cargo receivers)
- The end result will be enhanced mobility and quality of living for urban dwellers and society.

6.2.1.3 Mobility2.0

The Mobility2.0 is a project that is co-funded by the European Commission DG-Information Society and Media in the 7th Framework Programme. It started on September, 2012, and will conclude on February, 2015. Focus will primarily be on the development of co-operative commuting assistant for Electric Vehicles. This guidance application shall:

- Optimize overall commute time
- Intelligently manage priorities at public recharging spots
- Facilitate traffic peak mitigation through dynamic electricity pricing

Mobility2.0 will develop and test an in-vehicle commuting assistant for FEV mobility, resulting in more reliable and energy-efficient electro-mobility. In order to achieve a maximum impact, Mobility2.0 takes an integrated approach of addressing the main bottlenecks of urban FEV mobility: 'range anxiety' related to the limited FEV range, scarcity of parking spaces with public recharging spots, and the congestion of urban roads. The integrated approach means the application developed by Mobility2.0 will utilise co-operative systems to simultaneously consider these bottlenecks, so that such an optimisation can be achieved which still guarantees reliable transportation for each FEV owner.

6.2.1.4 eMI³

Under the umbrella of ERTICO – ITS Europe, the eMobility ICT Interoperability Innovation, eMI³, is an open group of significant actors from the global Electric Vehicles market who joined forces to harmonize the ICT data definitions, formats, interfaces, and exchange mechanisms in order to enable a common language among all ICT platforms for Electric Vehicles.

eMI³ core objectives lie in the development, publication, sharing and promotion of ICT standards. However the project just started and have not yet defined use-cases. Hence no detailed synergies can be identified at this stage even if they most probably can be found when the eMI³-project has reached further.

6.2.1.5 **mobincity**

Mobincity is a project funded by the European Commission under the Seventh Framework Programme (ICT for fully electric vehicles). It started July 2012 and will end June 2015. During this time the consortium will develop a system to be installed within FEVs that is able:

- To receive information from the surrounding environment (e.g. traffic or weather information) which can have influence on the vehicle performance
- To optimise the trip planning and routing of FEVs adapted to user's needs by using information from external sources including alternatives from other transport modes
- To define efficient and optimum charging strategies (including routing) adapted to the user needs and grid conditions
- To implement additional energy saving methods (as driving modes and In-Car Energy Management Services) within the FEV interaction with the driver.

6.2.2 Suggested synergies

The following services have been defined and possible synergies have been identified:

- Loading/unloading zone booking <=> Charger booking
- Automated access <=> Automated charger access (when no billing systems are needed)
- Dynamic time/place drop point <=> Suggest drop point at charger
- Traffic zone control <=> Differentiate charger booking and/or energy price
- Green Corridors <=> Differentiate charger booking and/or energy price
- Urban optimized fleet management <=> Take limited driving range into account

In the next chapters the identified synergies are briefly described.

6.2.2.1 **Loading/unloading zone booking <=> Charger booking**

It is not obvious weather or not it should be possible to book an en-route static charging station. The charging time should be five minutes or less so from that perspective it does not make much sense to book a charging event but on the other hand in some situations the queue for the charging may be long hence it could still be efficient to be able to book a number in the cue.

It would make sense to start from the same scenario as defined for managing booking of stationary conductive charging e.g. *UCTP0104 Integration with Parking Booking System*; *UCTP0203 Parking Lots Reservation* and *UCIE0103 Scheduling the charging*) of mobincity[8]. Then it could be adapted to commercial vehicle requirements similar to the ones defined for loading/unloading in Instant Mobility[9].

6.2.2.2 **Automated loading access <=> Automated charger access**

The automated access control & security check is a service for streamlining the inbound traffic to hubs such as ports and terminals by eliminating the need of manual checking and authorization of access rights to restricted zones for goods, vehicle and driver.[10]

For commercial vehicles with their own driving lanes like BRT (bus rapid transfer) and where the charging equipment are only supposed to be used by predefined customers/vehicles, there is no need for a traditional billing system. Instead it would be enough if the vehicles' individual energy consumption could be tracked and that the charging infrastructure only tries to charge vehicles with the correct charging equipment. This scenario have synergies with the scenario defined for *Service 4d: Automated access control & security check* in Instant Mobility in a sense that only authorized vehicles are allowed access to the charger.

6.2.2.3 **Dynamic time/place drop point <=> Suggest drop point at charger**

In *service 4e: Dynamic time/place drop point* the aim is to increase the flexibility in the delivery of goods by launching a service that dynamically points out the right time and place for delivering every single package. The service is using feedback/info from the consignee, traffic and other issues in the city center under the concept that everything and everybody is "pingable.[11]

Since packet drop off means vehicle standing still for a short period of time this could be a perfect opportunity for static en-route charging as defined by the Unplugged project. Hence it would be beneficial if the agreed drop point could be at a charging point and the predicted time and place-information be shared with the on or off-board energy/power management system.

6.2.2.4 **Traffic zone control <=> Differentiate charger booking and/or energy price**

In *service 4f: Traffic zone control* the service will automatically control that the vehicles entering a specific zone is allowed to be there. A restricted zone could be a city-centre where traffic is allowed only during certain hours. If not allowed in the zone, appropriate measures will be taken; examples of such measures can be to, as in the example, notify the driver of the restrictions or perhaps issue a fine for not adhering to the restrictions. ".[12]

If one would differentiate charger booking and/or energy price so that, in certain zones, it will take longer to charge and that it costs more you could control (at least BEV and PHEV) traffic flow and vehicle use. Since this is one purpose of *service 4f: Traffic zone control,* there are synergies to be explored.

6.2.2.5 **Green Corridors <=> Optimized charger booking**

In *Service 4g: Green corridors* the concept is referring to a number of dynamic (based on need, availability and capacity) features which provide a virtual environment for green transport through/within the city to/from hubs and harbors. The GC consists of the following services:[13]

- Optimized routes and efficient driving guidance
- Optimized flow of incoming and outgoing goods
- Efficient throughput and higher possibility for monitoring and differentiation of service level

There are many expected benefits of establishing green corridor functionality through/within cities. The traffic can be planned and routed based on real-time traffic, itinerary data and charging needs, reducing congestions, noise and air pollutions. This has mainly social and environmental impacts but enhanced information can also help truck drivers and fleet operators plan the transport missions to become more safe and efficient. If a truck for example does not have to be in the harbor at its estimated ETA, the driver may stop at a charging point and perhaps also have a rest.

6.2.2.6 ***Real time traffic optimized route navigation*** **<=> Include BEV limitations**

In *Service 4h: Real time traffic optimized route navigation* the navigation system of a distribution vehicle provides the driver with directions based on real time information about the traffic situation near the vehicle. The information which the system bases its routing decisions upon comes from various sources such as traffic planners and the emergency service, but also from other vehicles equipped with compatible systems.[14]

The information from other vehicles in the vicinity of the distribution vehicle provides accurate information on the traffic situation. Information which the vehicles communicate is for example their average speed, break/throttle usage and charging need. The infrastructure itself can also provide useful information. The information is aggregated and used to provide the most efficient route, taking into account e.g. fuel economy, time consumption and risk of accidents. With input from Mobility2.0[15] and mobincity also charging need and charger availability could be taken into account to provide the most efficient route. Additionally the regulation (3820/ 85) on driving and resting times could be combined with the other information to better estimate total time consumption and plan suitable charging events.

7 Conclusion

In this document many aspects of the wireless charging technology have been analyzed, in order to evaluate the impact of the technology on the automotive side, both from a technical point of view and from a user perspective.

From the technical point of view analyses performed along the document demonstrates that wireless charging could be a key-technology for Electric Vehicles diffusion.
“Range anxiety” can be strongly reduced adopting this technology, at least for urban environment.

Analyses performed into the first chapter demonstrates the great interest in studies and developments to improve traditional and alternative storage systems, moved by e-Mobility and proposes the wireless charging as a technology to overpass some of the limits of batteries system: weight, cost, charging time.
Driving cycle simulations and evaluations demonstrate real traffic environment could be also more advantageous for wireless charging.

Regarding the interaction with the infrastructure, the theme is very innovative and very few studies have already been published; the creation of a model to evaluate the impact of the vehicle on possible “en-route” or dynamic infrastructure is only the first step toward on-road integration.

Feasibility of the mechanical integration, especially for small vehicle has been demonstrated.
Anyway, to find the best solutions, the design of new electric cars should start from zero, in order to take into account all the features and constraints of a pure EV and without being limited by traditional ICE vehicles.
From the electrical point of view the interaction is not an issue, but communications aspects between vehicle side and infrastructure side must be taken into account both for charging control aspects and data exchange. Furthermore, it is very important to consider safety mechanisms in case of missing communication.

Tests performed on the auxiliary systems to help driver to get the best positioning have demonstrated that simple devices, already present in automotive industry, can easily facilitate driving maneuvers and improve coils alignment and efficiency..

In the end an overview of the needs, opportunities and synergies with other projects related to the e-Mobility has been presented.

8 Annex 1

8.1 Ultracapacitors and flywheel additional analyses

8.1.1 Ultracapacitors technical description

8.1.1.1.1 Electrolytic Double Layer Capacitors (EDLC):

EDLC's store energy like the conventional capacitors, i.e.by polarizing the electrolytic solution, without charge transference between electrodes and electrolyte. These are the most common commercial ultracapacitors, composed of two carbon electrodes, an electrolyte and a separator. The energy is stored in the double electrolytic layer. As the voltage is applied, the charge is stored on the surface of the electrodes.

The electrolyte ions are diffused through the separator and distributed among the pores of the electrodes without recombination. The combination of high surface area and separator thickness allows this technology to reach higher energy densities than conventional capacitors. There are three main material technologies behind ELDCs:

- Activated Carbon: the material commonly used for the electrodes; the investigation in this category is based in determining the factors that contribute to improve capacity, usually by increasing the surface area through optimization of carbon pore size distribution, and to reduce internal resistance of materials.
- Carbon nanotubes: grown as an entangled mat on the electrodes made of this material, exposing a bigger area and achieving even higher capacity than using activated carbon material; further improvement can be achieved if nanotube mat is made from activated carbon.
- Carbon Aerogels: obtained by pyrolyzing an organic compound in an inert medium. This process removes everything except the carbon and leaves behind so-called solid smoke. The huge surface areas of aerogels, and tiny pores, imply high capacitances. Operated at 2.5 V, such ultracapacitors can store energy at a density of 90 Wh/kg, not so far from that of the most advanced lithium-polymer batteries (that are still under development). Power densities are as high as 20 kW/kg. At present, small aerogel ultracapacitors are used in electronic equipment, but in the future, they could prove suitable for higher-voltage and higher-power applications, such as electric vehicles.

8.1.1.1.2 Pseudo capacitors:

In contrast to electrostatically driven capacitors, pseudo capacitors store charge faradaically, that is through transfer of charge between electrode and electrolyte; therefore they represent an evolution of ultracapacitor technology towards electrochemical batteries.

Highly relevant capacities and energy densities can be achieved, even better than what was attainable by ELDCs.

The main materials commonly used as electrodes are:

- Conductive Polymers: they store and discharge their charge through reduction-oxidation processes. In the conductive polymeric films, the charge exchange is generated in the whole volume of the film instead of only the surface, increasing capacity while keeping a relatively low internal resistance (ESR). However, the mechanical stress on polymers during reactions limits the stability of these capacitors through many charge-discharge cycles. This reduced cycling stability has hindered the development of conducting polymer pseudo capacitors.
- Metallic Oxides: thanks to its conductivity and high specific capacity, these capacitors can reach high energy and power densities. Most of the investigations are focused on the Ruthenium Oxide (RuO_2) material which offers average capacity values, but with prohibitive cost, only affordable in specific military application. Thus, a major area of research is on the development of fabrication methods and composite materials to reduce the cost of ruthenium oxide, without reducing the performance, but is limited by the type of electrolyte to be used.

8.1.1.1.3 Hybrid capacitors:

The hybrid electrode configurations consist in the combination of two electrodes made of different materials (from the two previously described technologies), trying to explore the advantages of the double layer capacitors and the pseudo capacitors. Thus, it is possible to obtain products with more energy density, but due to Faradaic reactions that take place in one of the electrodes, the round trip cycle (charge/discharge) efficiency can be only 75-90%, providing an increase of power values but not proportional to the energy increase.

- Composite hybrids: combine into same electrode two different types of material. The increase of capacity takes place along the whole volume of material, the carbon nanotubes and the polymer structure.
- Asymmetric hybrids: result from investigations to overcome the lack of an efficient negative charged polymeric electrode in pseudo capacitors. The asymmetric hybrids combine one electrode made of active carbon and the other made of polymeric material; the result is an increase of the stored energy compared with EDLC's and better cycle stability than pseudo capacitors. This technology has enabled some manufacturer to achieve big improvement of capacitor characteristics.
- Battery-type hybrids: combined electrodes used in electrochemical batteries with ultracapacitor electrodes (active carbon), hence they are also known as "bacitor" (battery-capacitor).

8.1.2 Flywheel technical description

8.1.2.1 Technical considerations

For decades, most engineers have used the concept of storing kinetic energy in a spinning mass to smooth their operation. Until recently the vast majority constituted of steel wheels coupled with a motor/generator, where the high rotary inertia allowed long ride-through time without significant decrease in flywheel rotational speed. Since the change in rotational speed directly reflects the electrical frequency, the power delivery of those flywheels rarely exceeded 5% of the stored energy.

8.1.2.2 Motor/generator

Requirements for standardized electric power have made most flywheel system designers elect variable speed AC generators (to accommodate the gradual slowing of the flywheel during discharge) and diodes to deliver DC electricity. The two major types of machines used are the axial-flux and the radial-flux permanent magnet machines (AFPM and RFPM, respectively). The axial machines seem to have more advantages over the radial, such as a planar adjustable air gap and easy cooling arrangements, which is important when working under low-pressure conditions. Figure 93 (a) shows a one-rotor two stator AFPM configuration without the cable winding in the stators. It can be seen that the permanent magnets are an integral part of the flywheel rotor and the stators are fixed to the housing.

The radial flux machine is mostly used in small-scale high-speed machines, where the tensile strength of the permanent magnets demands placing close to the rotating axle.

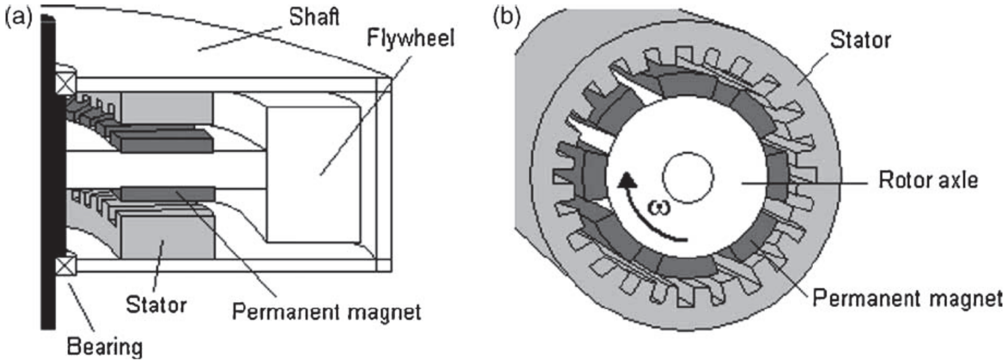


Figure 93: Possible electric machine designs for flywheel rotor: axial type (a) and radial type (b)

Another type of motor/generator is the internal-dipole, Halbach-type magnet arrays, where the PM array rotates with the flywheel and interacts with a set of stationary coils to produce torque. In a Halbach array, n PM segments forming a cylindrical shell about an axis create the internal dipole. One of the advantages of this configuration is the low external magnetic field produced when a steel rim is placed outside the magnets, while within the shell a dipole configuration creates a uniform flux.

Apart from the PM motor/generator used in almost all flywheels, also other technologies are possible, for instance Synchronous Reluctance Motor/Generators have been successfully developed.

8.1.2.3 **Number of poles**

The choice of number of poles to be used in a machine is essential to the overall performance. Two pole motor/generators are most common in high-speed machines, mainly to keep the voltage down. Depending on axial or radial flux configuration a multi-pole rotor can experience substantial electromagnetic axial or radial forces generated by the stator winding, if there is a net attractive force between a pole-pair and the stator. In a two-pole rotor, however, only two poles are directly opposite one another, resulting in a net force on the rotor of approximately zero. Eliminating these forces reduces the load requirements on the bearings, which is particularly important if magnetic bearings are used.

8.1.2.4 **Magnetic bearings**

Standard mechanical bearings cannot, due to the high friction and short life, be adapted to modern high-speed flywheels. Instead a permanent or electro permanent magnetic bearing system is utilized. Electro permanent magnetic bearings do not have any contact with the shaft, has no moving parts, experience little wear and require no lubrication. Permanent magnets support the weight of the flywheel by repelling forces, and electromagnets are used to stabilize the flywheel, although it requires a complex guiding system. An easier way to stabilize is to use mechanical bearings at the end of the flywheel axle, possible since the permanent magnet levitates the flywheel and, thus, reduce the friction. The best performing bearing is the high-temperature super-conducting (HTS) magnetic bearing, which can situate the flywheel automatically without need of electricity or positioning control system, but requires cryogenic cooling (for instance by liquid nitrogen).

8.1.2.5 **Power electronics**

A brushless permanent magnet generator produces variable frequency AC current. In most applications though, the load requires a constant frequency making it necessary to first rectify the current and then convert it back to AC by power inverters, typically based on IGBT switches and controlled in PWM modulation. Electromechanical energy conversion systems have been explored in order to make them more fault-tolerant. By using three single-phase inverters instead of one compact setup, a more flexible design is achieved along with advantages like the ability to operate even in the event of a single-phase fault.

8.1.2.6 **Losses**

Generally speaking, electric machine losses in flywheel operation can be classified as stand-by losses and operating losses.

- Stand-by losses are always present as the rotor rotates, even when the outside environment is at rest, so they must be kept as low as possible in order to keep the stored energy level in stand-by conditions.
  The integrated motor/generator works thanks to the principle of the rotating magnetic field, where the field is supplied either by electromagnets or by rare-earth permanent magnets. The properties of high field permanent magnets yield flux densities high enough to enable machines without a magnetic stator core. Absence of a ferromagnetic material in the stator has two major impacts on the performance of a motor/generator: the low permeability will quickly reduce the magnetic field strength when moving away from the magnet, and there will not be any heat loss in the stator

core due to hysteresis effects (related to alternating magnetic flux effects on characteristics of ferromagnetic materials). These losses will have severe impact during long time (stand-by) energy storage in a flywheel. Without hysteresis loss the stand-by losses are very small and limited to those of leak eddy currents and bearing losses.

- Operational losses are present only when the machine is operated as controlled by the inverter, and windings interact with permanent magnets in order to produce torque, and determine the efficiency of the energy conversion of the flywheel KERS.
  Traditionally used ferrites do not, due to their low conductivity, give rise to induced eddy currents on the surface, while some of the sintered rare earth materials suffer such problems due to their large conductivity. Eddy currents on the surface of the magnets arise when the magnetic field from the stator interacts with the magnets. Since magnetic flux is proportional to the current going through the stator windings and eddy current losses are squarely dependent on frequency, it is necessary to minimize the current harmonics.
  A great deal of the total losses from the motor is joule (ohmic) losses in the stator winding. It is clear that those can be diminished either by increasing the amount of conducting material, thereby decreasing the resistance, or by decreasing the current in the stator. There are obvious drawbacks associated with increasing the amount of conducting material such as increasing weight, cost and space. Induced high frequency eddy currents in the stator may also increase depending on the configuration. Decreasing the current in the stator inevitably leads to higher voltage if the overall power is to be maintained (obviously, if a higher voltage can be handled the copper losses can therefore be decreased).

8.1.2.7 External gyroscopic aspects

For flywheels situated in a vehicle, satellite or space station, the gyroscopic forces are important. A way to cope with the interaction of gyroscopic forces in a vehicle when using just one flywheel is to place the flywheel in a gimbal system, thereby eliminating most of the gyroscopic torque. The gimbal system works in the same way as a cup-holder does in a vehicle, which means that the vehicle can turn and lean without tilting and twisting the position of the flywheel.

8.1.2.8 Safety

Inertial containment becomes necessary to minimize the collateral damage from a failed flywheel, which is a safety issue to be carefully considered. Reasons for failure could be crack growth from material flaws created during manufacture, bearing failure or external shock loads. For large flywheels the vacuum chamber acts as a first safety enclosure in a multiple-barrier containment system to prevent rotor debris from flying free, but small portable flywheels cannot utilize bulky containments. In such cases the rotor is usually designed to fail safely, in which case a vacuum vessel provides sufficient protection. Most machines have a vertical rotation axle, but horizontal machines also occur. A vertical axle minimizes the possibility of mass centre displacement which can lead to instabilities and damage the flywheel.

9 Annex 2

9.1 Duration and Power of charging process

9.1.1.1 Slow (or Regular) Charging

Regular charging is the basic form of charging and is done directly from the existing grid. This is a time excessive form of charging and it requires that the car will be out of use for several consecutive hours in order to reach a full-charge. It is mainly during nights (for over six hours) and daytime at work the car is not used for this amount of time and it is highly probable that regular charging only will be used under these circumstances.

The EV batteries can be charged by a rather low charging current, from 10 A to 16 A. The operation and installation costs of the corresponding charger are relatively low since the power and current ratings involved are not of critical values.

The existing infrastructure for regular charging is basically already in place, especially if house areas and larger companies parking lots are considered. Many houses today provide garages, car ports or driveways connected to the grid, today used for motor heaters. The same conditions apply for major parking lots; these motor heaters can easily be converted to regular charging spots.

In the city centres on the other hand there is a need for a more developed infrastructure; overnight parking is often done along the pavement or in public parking lots. The common parking lots provide similar opportunity as the company parking lots. In this case a system that handles access to charging equipment must be created. Considering parking along pavements, it is more problematic since there are regulations that have to be followed to higher extent. These regulations concern for example accessibility and maintenance.

9.1.1.2 Semi-Fast Charging

This charging alternative will be a good alternative when the EV owner will spend a certain amount of time at a place, estimated between 1-3 hours, which is shorter than the time needed for regular charging.

The EV batteries can be charged by a medium current of 30-60 A. The operation and installation costs of the corresponding charger are relatively higher than that for normal charging current because of the necessity to upgrade the charging equipment.

Some studies have shown that the primary reason that a vehicle is used is linked to leisure activities. This means that the driver will stop at one location for a longer amount of time leaving the EV out of use. With the help of semi-fast charging at these leisure places the charging can be done at the same time while other things are taken care off. A fully charged vehicle will just be a benefit of family week-end trips or weekly shopping.

There is no need for an additional stop on the way home and the driver does not have to manage the refuelling the batteries, the EV driver will just plug in the EV and then do whatever they want during the time the vehicle is charged.

The semi-fast charging will be an interesting alternative for shop owners since they have a large interest in having consumers wandering the store for two hours, this will set conditions for consumers to spend operating cost money saved on products and services related to the shop.

9.1.1.3 Fast Charging

More developed charging equipment and battery technology is required to enable batteries to be charged in 30 minutes. Even faster charging will be possible offering a fully charged vehicle in just 15 minutes or less. This form of charging require delta voltage and transformers will have to be installed (charging current of 150-400A), this mean that gasoline stations will not serve as obvious fast charging spots, but gasoline stations can be a good alternative considered their strategic placed position.

In contrast to that using normal or medium charging current, the corresponding charger offers relatively low charge efficiency. Certainly, the corresponding operation and installation costs are high.

Fast charging will probably only be used as secure alternatives in cities and in connection to major highways were other alternatives are unavailable. The positions and design will probably be similar to present gasoline stations.

In conclusion, the normal charging current are adopted in both domestic and public charging infrastructures, whereas both the medium and fast charging currents are only found in the public charging infrastructure. Moreover, the fast charging current should only be adopted in those dedicated public charging stations because the corresponding current demand may cause detrimental effect on the power system network and maybe increase the impact of large current on the battery life.

Also the estimated use of the vehicles will determine the kind of charging infrastructure more appropriate to optimize the infrastructure costs.

10 Annex 3

10.1 The Integration of Renewable Energies into the Smart Grid

In the same way that electric vehicles enable load shaping to increase utilization of installed generation capacity, renewable energies also enable greater adoption of intermittent energy sources by scheduling electrical loads to coincide with periods of strong wind or sun. Wind in particular is suitable for providing electric vehicle charging, as it tends to peak around dawn and dusk when vehicle recharging will be most convenient and affordable.

Another possibility is if EV batteries continue to increase storage capacity, excess power generated from utility scale wind power plants during the night could be stored in EVs and then used to provide power to the grid during the day.
A possible solution to use the surplus electricity is the production and storage as fuels.

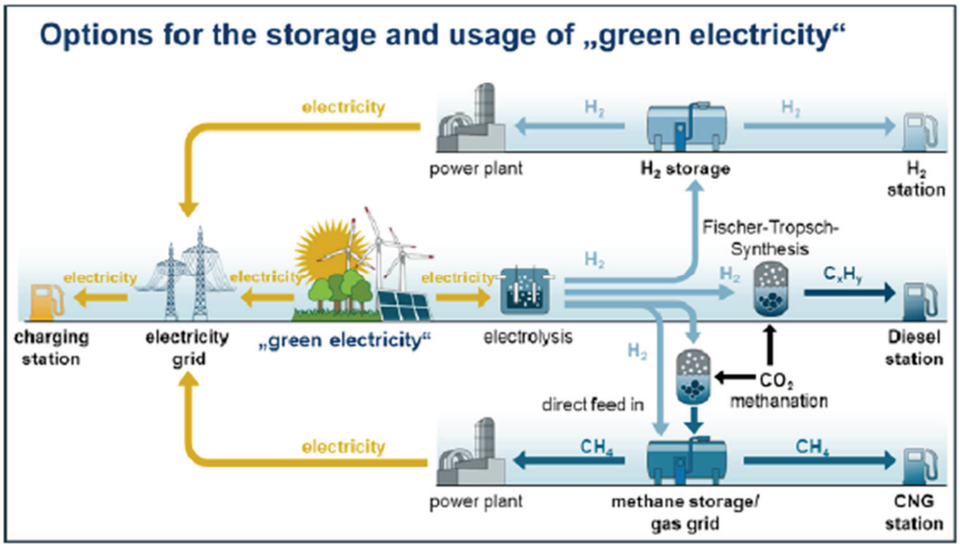


Figure 94: From surplus of electricity to fuel

Concerning fuels the transition of the energy system towards high penetrations of renewable energies results in even more possibilities to make use of green electricity. Load shaping through EVs and the subsequent use of the electricity in the car is the most efficient way (well-to-wheel), but the conversion of electricity into chemical energy carriers has important benefits as well.

These are namely the possible assistance of the electricity distribution grid and the reduction of otherwise necessary new construction of high voltage power lines in the short and medium term as well as the potential to utilize net generating surpluses from renewable energies in the long term (serving as long-term energy storage after 2025).

The chemical storage technology is based on electrolysis as its essential component, converting water and electricity into hydrogen, oxygen and heat. The efficiency of the process reaches 60% to 80%, depending on the utilized technology (Proton Exchange Membrane or Alkaline) and the required product properties (purity, pressure, etc.). The hydrogen produced can be stored and transported and then be used for re-electrification (given a price spread on electricity markets) in adapted power plants or as a fuel in FCEVs. In the long term, utilizing substantial net generating surpluses from renewable energies, this pathway may become highly important for sustainable long distance mobility.

In the short term though, with FCEV still being in research/ development state, there are two different potential pathways to utilize the hydrogen produced. They are direct feed in of the hydrogen into the gas grid or further transformation of the hydrogen into hydrocarbons that are consistent with present day ICE vehicles.

When feeding hydrogen directly into the gas grid, however, certain regulatory limitations and customer demands must be taken into account because of the multitude of requirements on fuel gas of different end user appliances (boilers, turbines, engines, stoves) and the distribution grid (gaskets, joints, compressors, pipelines, etc.).
This is due to the fairly different substance properties of hydrogen and methane with respect to for example heating value, Wobbe-Index, ignition boundaries, permeability and compressibility.

One potential pathway towards hydrocarbons is the methanation (efficiency from hydrogen to methane is about 60%) of hydrogen with carbon dioxide, producing a methane rich mixture of gases (containing CO_2 and H_2 as well) that meets the standards for natural gas and can thus be mixed to the gas grid without any restrictions. The well to tank emissions of the Substitute Natural Gas depends on the source of the CO_2, which can be either fossil (from power plants, cement plants or ironworks) or renewable (from biogas/bio-methane plants, breweries or bioethanol plants).

Another possible fuel from green electricity and CO_2 is synthetic diesel that is produced by Fischer-Tropsch-Synthesis. This process is, however, even more complex than the methanation and has a lower efficiency.

Essential challenges of today, to solve for further progress, are:

- Repercussion on the grid stabilization caused by a multiplicity of decentralized grid supply.
- The development of energy management systems for the consumer with a wider range than only smart metering, able to communicate and steer installation up to the small management of in/out of other energy like solar energy.
- Optimization, also of the dimension, of the electricity grid because of the integration of a lot of different producers/consumers up to electrified vehicles.

Smart Grid could be the enabler for new technologies, for e-mobility as well as for renewable energy sources such as solar or wind .

But different levels of technology will involve different costs. Optimization and standardization will eventually be necessary.

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