FABRIC

Feasibility analysis and development of on-road charging solutions for future electric vehicles

Task 3.3.1 Review of existing power transfer solutions

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Authors		Mehmet Emre (TRL), Peter Vermaat (TRL), Denis Naberezhnykh (TRL), Yannis Damousis (ICCS) Theodoros Theodoropoulos (ICCS), Vincenzo Cirimele (Polito), Angelo Doni (Saet)	
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LIST OF SELECTED ABBREVIATIONS

ABBREVIATION	DESCRIPTION
2G	2nd generation mobile communication standard, GSM
3G	3rd generation mobile communication standard, UMTS
3GPP	3rd Generation Partnership Project, unites telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TTA, TTC)
4G	4rd generation mobile communication standard, LTE
AC	Alternating Current
ADSL	Asymmetric Digital Subscriber Line
APS	Aesthetic Power Supply
CALM	Communications access for land mobiles,
CAMS	Computer Aided Maintenance Systems
CISPR	Comité International Spécial des Perturbations Radioélectriques
CRF	Centro Ricerche Fiat
CS	Charging Spot
CWD	Charge While Driving
DC	Direct Current
DATEX	Data Exchange
DOE	Department of Energy
DSM	Demand Side Management
DSO	Distribution System Operator
DSRC	Dedicated Short Range Communication
EETS	European Electronic Toll Service
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
ERS	Electric Road System
ESD	Electrostatic Discharge
ETC	Electronic Toll Collection
ETIS ITS G5	ETSI standard (ETSI EN 302 663) for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band, based on IEEE 802.11p
ETSI	European Telecommunications Standards Institute

ETSI ITS	European Telecommunications Standards Institute Intelligent Transport System
European CEN	European Committee for Standardization
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FDD	Frequency Division Duplex, variant of LTE technology
FEV	Fully Electric Vehicle
FOT	Field Operational Test
G5	See ETSI ITS G5
GPRS	General Packet Radio Service
GPS	Global Positioning System, a GNSS developed by US Department of Defence
HMI	Human Machine Interface
HPSA+	High speed packet access, extension to HPSA
HSDPA	High speed downlink access, extension to UMTS, part of HPSA protocol family
HSPA	High speed packet access, extension to UMTS communication technology
HSUPA	High-Speed Uplink Packet Access, extension to UMTS, part of HPSA protocol family
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEEE 1609	Higher layer standard based on the IEEE 802.11p
IEEE 802.11p	Approved amendment to the IEEE 802.11 standard to add Wireless Access in Vehicular Environments (WAVE)
I2I	Infrastructure to Infrastructure communications
IP	Internet Protocol
IPT	Inductive Power Transfer
IPV	Induction Powered Vehicle
ISO	International Organization for Standardization
ISO TC 204	ISO Technical committee, is responsible for the overall system aspects and infrastructure aspects of intelligent transport systems, http://www.iso.org/iso/iso_technical_committee?commid=54706
ITS	Intelligent Transport Systems.
ITS G5	Intelligent Transport Systems operating in the 5 GHz frequency band
ITU	International Telecommunication union

KAIST	Korea Advanced institute of Science and Technology
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LTE	Long-term evolution, marketed as 4G LTE. Standard for wireless communication of high-speed data for mobile phones and data terminals
LV	Low Voltage
M2M	Machine to Machine
MAN	Metropolitan Area Network
MDC	Magneto Dynamic coupling
MIT	Massachusetts Institute of technology
MRL	Manufacturing Readiness level
NFC	Near Field Communication
NIST	National Institution of Standards and Technology
OBU	On Board Unit
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PAN	Personal Area Network
PB	Power Box
PC	Personal Computer
PCM	Pulse Code Modulation
PHEV	Plug-In Hybrid Electric Vehicle
PLC	Power Line Communication
POLITO	Politecnico Torino
PSOBU	Public Safety On Board Unit
RCD	Residual Current Device
RSU	Road Side unit
SDH	Synchronous Digital Hierarchy
SECC	Supply Equipment Communications Control
SMFIR	Shaped Magnetic Field in Resonance
SONET	Synchronous Optical Network

SotA	State of the Art
TETRA	Terrestrial Trunked Radio
TRL (company)	Transport Research Laboratory
TRL	Technical Readiness Level
UMTS	Universal Mobile telecommunications Service
UWB	Ultra Wide Band communications
V2I	Vehicle to Infrastructure communications
V2G	Vehicle to grid communications
V2V	Vehicle to Vehicle communications
V2X	Vehicle to Anything communications
WAN	Wide Area Network
WAVE	Wireless Access in Vehicular Environments
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WPT	Wireless Power Transfer

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
1	16/10/2014	Draft for internal review
2	7/11/2014	Final draft for internal review
3	14/11/2014	For project peer review
4	12/12/2014	V1 for submission
5	15/05/2015	V1.1 final submission, following client review

EXECUTIVE SUMMARY

This document is a review of the state of the art in existing power transfer solutions. The FABRIC project focuses on dynamic power transfer, but as many dynamic power transfer solutions are being developed from existing static solutions, this review considers all power transfer systems. The review also includes state of the art in communications systems for on-road charging solutions, as well as the results of a market readiness survey.

Power transfer systems are considered in three categories:

- Static power transfer, where power is transferred to a vehicle which is stationary, and expected to remain so for a significant time. This type of system is typified by a parked vehicle. In these systems it is acceptable to require the driver to make a conscious decision to commence charging.
- Stationary power transfer, where power is transferred to a vehicle which is stationary for a short time, for example at a bus stop or taxi rank, or even when queuing at a junction. In these systems it is expected that charging will happen automatically with driver intervention. As connection times are short, power transfer rates need to be higher than for static charging.
- Dynamic power transfer, where power is transferred while vehicle are moving in normal traffic.

While most dynamic power transfer systems currently in development are wireless, some conductive systems are being developed and these are also covered in this review.

Nearly all wireless charging systems currently being developed use magnetic resonant induction as the means of transferring power. Inductive power transfer uses the principal that if two coils of wire are placed in close proximity, then if alternating current (AC) power is applied to one coil, power can be drawn from the second coil. This principal is used in power transformers where high power transfer efficiencies (in excess of 98%) are possible. To achieve these efficiencies at mains frequency (50 or 60 Hz), the two coils need to be in extremely close proximity (typically one coil is wound on top of the other) and the coupling between the coils is enhanced by placing a core with a high iron content through the centre of the coils. As neither close proximity nor an iron core are possible in a dynamic charging environment, efficiency is maintained by operating the coils at a high frequency (tens to hundreds of kHz), and operating both the coils in a resonant mode. Using these techniques, power transfer efficiencies of over 80% are possible.

Dynamic wireless systems generally operate from a three phase 400VAC Low Voltage feeding point from the distribution network. For the majority of the reviewed systems, the supply voltage is converted to a high-frequency, high voltage supply for wireless power transfer. This is typically 750 VAC operating at several tens of kHz. Power transfer efficiency for static systems can be as high as 95%, but in dynamic systems, efficiencies are relatively lower; for example the KAIST system's efficiency is between 75 and 80% in dynamic mode. The power transfer frequency for dynamic systems is below 30 kHz, and the frequency for static systems can be as high as 145 kHz. The air gap for dynamic systems can be high as 270 mm and the lateral misalignment in dynamic systems can have a tolerance of up to 500mm depending on the system.

The power transfer rate can be as high as 200 kW, but collection of power at this rate may require large and heavy (on-board) secondary coils, which may not be mechanically suitable for cars. Secondary coil power rates are typically between 15KW-50KW and operating a number of these coils in an array could result in higher power transfer rates. The coil dimensions for a 100 kW secondary coil array is approximately 1.8m in length by 1 metre in width, and it could weigh up to 330 kg. A single pick up coil with power electronics could weigh up to 100 kg. The length of a primary power transfer coils/loops can range between 1.5 metres and 24 metres for the KAIST system.

FABRIC applications will be based on both short-range (local-area) and long-range (wide-area) wired and wireless communication technologies. The most prominent representative of short-range wireless communications are vehicular ad-hoc networks, like ETSI ITS-G5, based on IEEE 802.11p. These technologies may be used also for short-range V2I communication. For long-range communications, cellular networks such as 2G, 3G and LTE are potential mediums as well as using the power cables. Communications systems will need to be an integral part of any standardisation activity as a reliable, efficient communications subsystem is required to implement a successful dynamic charging system.

The ability of the market to supply various types of charging infrastructure was evaluated by means of a market readiness survey. While the number of respondents to the survey was too low to draw statistically significant conclusions, the survey still provides a useful input to what the state of the market, and the expectations for future maturing of the technologies involved.

Static wireless charging is technologically the most mature solution. It which has been tested extensively and the related products are ready to reach the market in sectors like home

charging and corporate environments. Major vehicle manufacturers and OEMs are expected to provide wireless charging stations and EVs within the next one or two years. Operational and interoperability issues for widespread exploitation in public environments are still to be resolved.

Stationary wireless charging is a technologically mature solution, though less so than static systems, which has been extensively tested for buses. The EVs and infrastructure products are already marketable and their commercial exploitation has begun. As with static charging, operational and interoperability issues for widespread exploitation in public environments are still to be resolved.

With the exception of one supplier who is currently running an operational fleet of buses, dynamic charging technology is still in its R&D phase. A number of companies are actively developing dynamic wireless charging solutions, both in the research and testing phases.

To ensure that a vibrant market exists for dynamic wireless power transfer, multiple manufacturers should be able to provide competing systems. However to gain widespread acceptance, It is generally accepted that systems will need to be interoperable to allow vehicles to make full use of the available charging infrastructure. While the core technology is similar for all the systems considered, the systems are incapable of interoperating due to differences in operating frequencies, power levels and circuit topologies. Significant standardisation work will be required to make systems capable of interoperating, but these standards must not be such that they stifle innovation.

The market readiness survey also indicated that, while both the technical and manufacturing readiness levels are such that the systems are not yet ready for production, the respondents indicated that the system would mature significantly within the next year.

Conductive dynamic charging is being tested on regular roads but commercialization is expected to take more time due to the significant investments required to transform normal roads to electric roads. Safety and aesthetic concerns mat make conductive systems less viable.

1 INTRODUCTION

1.1 General

This document is the deliverable D 3.3.1, “Review of existing solutions” as stated in description of work. This report reviews the state of the art for on-road power transfer solutions, which can be wireless or conductive, and potential solutions that could be re-engineered to operate in on-road mode. The report also covers the state of the art in communications, such as feasible communication options between different stakeholders.

Figure 1 shows the dependencies on deliverable 3.3.1. The results from this report feeds into deliverable 3.3.2 “the GAP analysis” in order to compare the state of art against the requirements and expectations from the users and the stakeholders.

This review includes power solutions from FABRIC project partners as well as systems developed by the organisations outside of FABRIC consortium. Even though FABRIC aims to develop on-road power transfer solutions, this report also reviews static solutions which could be modified to operate as an on-road power transfer system.

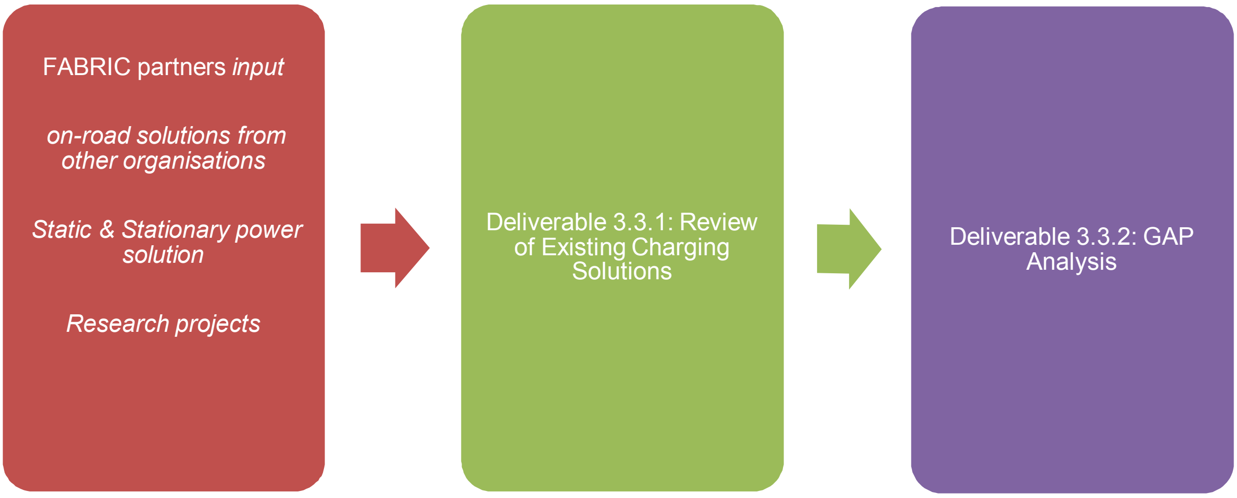

Figure 1: D.3.3.1 dependencies

The second chapter introduces the physical theory of power transfer. This is followed by a high level investigation into standards, regulations and guidelines that could be applicable to dynamic power transfer.

The third chapter reviews the state of art in communications used in on-road charging solutions, such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicle-to-Grid (V2G) communications.

The fourth and final chapter is a review of existing power transfer solutions from FABRIC project partners, other on-road systems, static solutions and research projects. The review of each power transfer solution is divided into three sections: outline, specification and installation & maintenance. The outline section includes background information, such as energy transfer method, deployment, layout from grid to vehicle. The specification section includes technical parameters of the system such as operating voltage, frequency, efficiency and physical parameters. The installation & maintenance section reviews the civil engineering aspects of the solution.

Organisation roles and responsibilities:

- TRL – work package coordinator and reviewing charging solutions from organisations that are outside of FABRIC consortium, focusing on Europe and the US, covering solutions and standards.
- FKA – to use and build on the review of existing charging solutions (including stationary) that would have been undertaken as part of the UNPLUGGED project.
    - Note: in order not to duplicate any work it is important to identify what has already been looked at and focus on identifying changes and modifications to those solutions. Should look to utilise existing contacts and sources where possible.
- CRF – to undertake a review of on-road charging solutions based on the systems CRF has previously investigated.
- POLITO – to provide an input based on the developed prototype and other charging solutions reviewed and investigated during development. Undertake review of relevant systems and standards in Asia.

- Volvo – provide an input into the review based on Volvo's existing conductive solution and other solutions review in previous projects for buses and trucks
- Scania – provide an input into the review based on Scania's trialled Bombardier solution and any other solutions investigated previously for buses and trucks
- Vedecom – provide an input based on the Qualcomm solution
- ICCS – to provide an input on the state of the art in communications used in on-road charging solutions and other charging solutions (covering local communications, i.e. between primary and secondary sides, as well as networking / back office communication).

1.2 Methodology

The initial study is analysing the theory and development of power transfer solutions. This section includes factors that could affect the power transfer rate and efficiency, as well as health and safety considerations. The review also studies patent applications and standardisation activities. In addition to the expertise of the project partners, online research, books and TRL's library services were used to source information for the review.

The second chapter is an investigation into the state of the art in communication technologies; this section was completed by ICCS with the feedback from TRL. The results are integrated into chapter 3 and chapter 4.

Chapter 3 investigates the power transfer solutions which have been used in real and experimental installations. TRL has developed a review template and requested following details regarding from all the identified solution providers.

Charging solution outline:

- Charging solution name
- System manufacturer / IP owner
- High level system description (how does it work, possible schematic/diagram)
- System type (wireless or conductive)
- On-road Charging capability (demonstrated capability, potential to develop dynamic system)
- Description of Key Components / modules (include diagrams if available)
- Application in other industries

- Approximate TRL level (Technology Readiness Level, level 1-9)[1]
- Existing installations / trials / demos
- Results available from testing / verification / certification (e.g. real life performance figures, impacts on CO2 and air quality, electric-only range of vehicles using the systems or EV utilisation, etc….)
- Overview of Capital, Operating and maintenance costs
- Actual or proposed deployment method (continuous, interval, all lanes, single lanes, speed restrictions, etc…)
- Effect on driving performance (e.g. vehicles oscillate as they enter/leave charge point)
- Foreign object detection (recognition of object between source and receiver)
- Foreign object removal method.

Electrical:

- Electrical parameters (Voltage, Current, Power Factor, Quality Factor (Q),
- Overall system Efficiency (Grid to battery, energy transferred into battery/energy received from the grid, load impedance)
- Operating frequency and Frequency range for wireless systems and conductive system if mode of power transfer is AC
- Power rating, power range
- Distance between supply feeds.
- Integration with grid (installation, connection point to distribution, LV? MV?, single or three phase)
- Air gap (distance between primary source coil to secondary on-board coil)
- Effective misalignment tolerance (X, Y, Z)
- Communication Protocol (ISO 15118, IEC 61851, OCPP, DLMS / COSEM)
- Communication method between subsystems for example vehicle to charger, charger to grid, infrastructure and back-office (e.g. LTE (4G), 3G, GSM, WLAN, WIMAX, Bluetooth, Zigbee, DECT, Enocean, DSRC)
- Information exchange between charging solution and vehicle (charge level, vehicle suitability, etc.)
- EMC

[1] http://www.innovationseeds.eu/Virtual_Library/Knowledge/TLR_Scale.kl

- EM exposure
- Harmonics
- Safety & Protection
- System topology (Series-series, series-parallel, parallel-series or parallel-parallel)
- Maximum allowable speed of the vehicle during charging
- Maximum power supply (number of vehicle a segment can provide power)
- Safety critical parameters (e.g. over current, over voltage, protection parameters)

Installation and Maintenance:

- Installation method (e.g. on/under the surface, roadside (PE) equipment)
- Installation time, cost and disruptions to road users (road closures, for example X km of road electrified in Y duration, road closure for X amount of days)
- Maintenance (methods, costs, duration, interval)
- Life time of the whole system
- Road surface requirement (A specific material the system works well or doesn't work well with)
- Distance between road surface and source coil (including depth under the road if embedded)
- Changes to the pavement structure, (location of charger unit in term of road layer)
- Structural integrity (maximum load capability)
- Friction/skid resistance (charging solution could have its own surfacing rather than ordinary road surface)
- Decommissioning (removing equipment, recycling, removing power connections)

Mechanical

- Physical dimensions / packaging (ground, road side and on-vehicle equipment)
- Coil dimensions and number of coils per segment (specific to wireless)
- Integration with vehicle (e.g. location on the vehicle)
- Operational tolerances (e.g. temp, vibration, pressure,)
- Ventilation / cooling (method)
- Coil/cable materials (e.g. chemistry; litz wire, copper,)
- Coil/Cable (life time of coil/cable due to heating and friction)
- Distance between booster transformer/feeder point
- Over Head Line clearance from the ground (conductive specific)

- Conductive wire clearance from the mast (conductive specific)
- Distance between two masts (conductive specific)
- Tension on the conductive cable (kN) (conductive Specific)
- Number of overhead cables (conductive Specific)
- Pantograph collector system (life time of conductors, fixed or tracking the source to maximise power, how do it react to lane changes)
- Overhead wire geometry (straight line or zigzagged between masts)

The state of art of power transfer solutions developed by FABRIC partners were completed by each responsible party. TRL has collaborated with the solutions providers to gather the most relevant information to ensure GAP analysis can be supported.

The investigation into power transfer solutions from organisations outside FABRIC consortium is a desktop study. The solutions providers' website, reports and theses are used to draft a section for each power transfer solutions. Once the review of a solution was completed, solutions providers were be interviewed via phone and email to populate the incomplete sections of the report as necessary.

2 EV POWER TRANSFER

The first electric vehicles (EVs) were in use in the mid-19th century and were initially very popular; 38% of the vehicles sold in 1900 used an electric drive train. Developments in internal combustion engine (ICE) technologies such as starter motors along, with the inconvenience of battery power transfer (long charging times, short range) rapidly reduced the market share of EVs to near zero. However, due to environmental concerns and the rising price of hydrocarbon-based fuels, EVs were back on the agenda for manufacturers in 1990s.

Figure 2 shows a simple layout of EV systems; as shown in the diagram, electric energy from the grid is transferred to the battery via a power converter which coverts AC grid supply to DC to charge the battery. The on-board battery acts as a source of energy for the traction motor(s) to drive wheels.

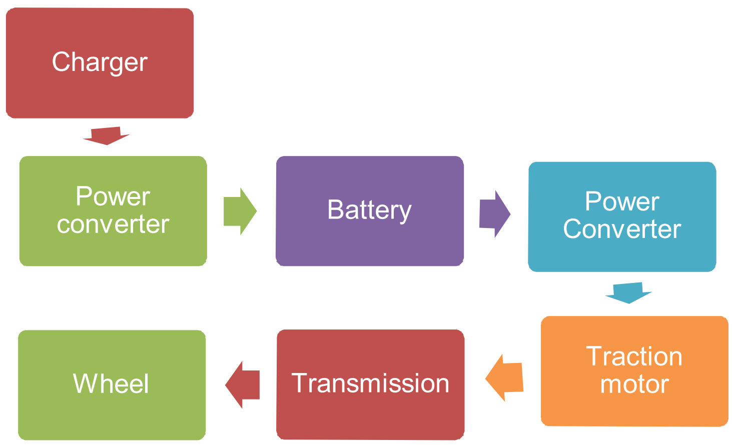

Figure 2: EV Layout

Power transfer solutions can be divided into two groups; conductive (plug-in or contact) or wireless. The majority of current power transfer solutions for EVs are static, plug-in systems, where the vehicle battery can be charged using a plug-in connector. These power transfer modes are capable of transferring power to a vehicle on various power transfer levels defined by the International Electrotechnical Commission. The duration of the power transfer can range from 20 minutes to 8 hours depending on the power transfer rate and battery capacity.

Plugin chargers are only suitable for static power transfer, therefore the electric car is required to stop and charge when the battery runs low. The short range of current electric vehicles (120km for a Nissan Leaf) and long time required for a full recharge, together with the limited number of charge points currently available results in range anxiety for users. This is a significant barrier for EV take up. While static wireless power transfer solutions are more convenient than plug-in solutions, they do not solve the range anxiety issues associated with short range and long recharge times, and they are even less numerous than static recharge points.

Dynamic (on-road) power transfer solutions have been developed and trialled by number of organisations with an aim to increase EV range, hence minimise the range anxiety, while minimising the cost and weight associated with large batteries. The on-road solutions can be conductive, similar to rail electrification or catenary systems, or wireless which transfers the power to a vehicle using a magnetic or an electric field. It is also possible to transfer power wirelessly by using laser or microwave but these technologies are very early in their development and have not been applied in transport to date, therefore, they will not be considered for further review in this report.

2.1 Types of on-road power transfer solutions

2.1.1 Magnetic Induction Power Transfer

Practically all existing high power wireless energy transfer systems use a resonant magnetic induction method as this approach currently provides the highest efficiency over an air gap. The University of Auckland was one of the first organisations to develop wireless power transfer for electric vehicles based on magnetic induction theory in the 1990s. General Motors developed their “Magne charge” system in 1996; this system was the first commercially available magnetically induced wireless energy transfer solution to transfer power to an EV (Chopra, 2011). The current state of the art inductive power transfer systems are capable of transferring power up to 200kW at 95% efficiency (for closely spaced coils).

Inductive resonant power transfer is based on the principle that if two conductors (typically coils) are in close proximity, an alternating current flowing in one conductor (the primary) will result in a voltage being induced in the second conductor (the secondary) thus transferring power from the primary to the secondary. The principle is the same as that used in

transformers. The efficiency of the power transfer depends on the inductive coupling between the two coils. In power transformers operating at mains frequency (50 or 60 Hz), this coupling is enhanced by winding both coils around an iron core, and keeping the two coils in very close proximity – typically one coil is wound on top of the other. Neither the use of iron cores nor maintaining very close proximity between the coils is possible in dynamic power transfer between in-road coils and moving vehicles; attempting inductive power transfer using 50 Hz mains power would result in extremely low efficiency. The efficiency of inductive power transfer between two relatively widely spaced coils can be dramatically improved using two techniques:

- Use a much higher frequency than 50 Hz – typically tens or hundreds of kHz – which minimises the need for an iron core.
- Make both the primary and secondary coils part of a tuned circuit, and ensure that the tuned circuits both resonate at the same frequency. Operating the inductive power transfer at this resonant frequency increases the efficiency of inductive power transfer between widely spaced coils.

Figure 3 shows a high-level layout of an inductive power transfer system. More details on the principles of IPT are described in the following sections.

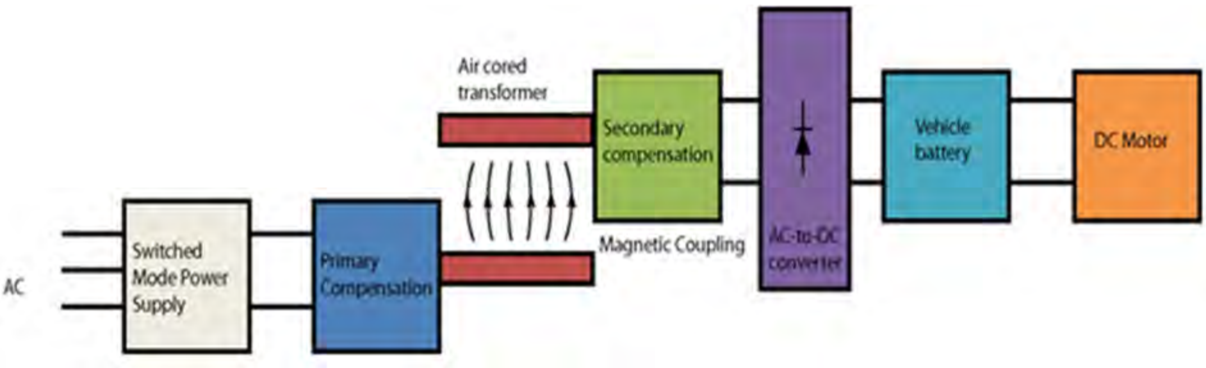

Figure 3: High-level example of an Inductive Power Transfer system layout

2.1.2 Electrostatic Power Transfer

Electrostatic power transfer, also known as Capacitive Power Transfer (CPT), is based on transfer of power through electrostatic induction. CPT works by placing two conductive plates closely together under high frequency AC voltage. CPT has significant advantages over IPT such as;

- The power transfer is continuous even if there is a metallic material between transmitter and pickup
- Radiated fields are confined between the plates, therefore, EM exposure and EMI issues are minimal
- Smaller in size and weight when compared with magnetic resonant system. (Prasanth, 2012).

The main disadvantage of CPT system is that it is very difficult to induce high enough electric field strength to generate large power transfer through the air gap; the permittivity of electric fields in air is very low compared to permeability of magnetic field (Pantic, 2013). Figure 4 shows a high-level CPT system, the energy is transferred between the two plates in form of an electric field. No existing power transfer solutions for high power applications based on CPT have been identified, therefore, this technology is not considered in this review.

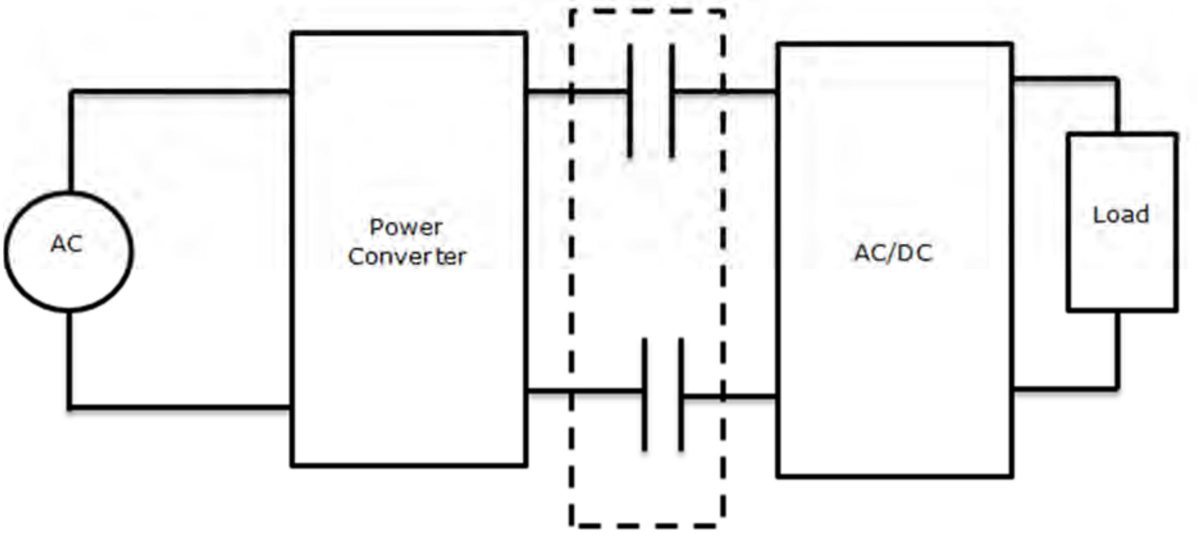

Figure 4: An example of an Electrostatic Power Transfer concept

2.1.3 Conductive Power Transfer

Conductive solutions for dynamic energy transfer systems are based on a physical contact between power supply source and the vehicle via a current collector pantograph. The power can be supplied through a set of overhead cables supported by series of masts along the road side or a wire/rail system running along the road and flush with the pavement.

The advantages of conductive systems are that it is proven technology being widely used in trams, trolleybuses and rail. The efficiency of the conductive systems is higher when compared with wireless solutions and the electromagnetic fields and exposure are far better controlled in conductive systems compared with wireless power transfer systems.

The disadvantages of the conductive systems are visual pollution, maintenance costs due to the sliding contact between the conductor and the collector, and safety issues caused by the exposed live wire/rail. The vehicle size is an issue for cars and vans as it is difficult to design a current collection system to reach overhead lines for all vehicles from cars to double-decker busses and HGVs. Road side systems using a live rail have significant safety issues.

2.2 Standards Regulations and Guidelines

Electric vehicles involve a number disciplines and as such there a number of international organisations working on standards and guidelines, including IEC, ISO, ICNIRP, CISPR11, ITU, ETSI, SAE, IEEE and national bodies.

The standards for dynamic power transfer can be grouped in following order;

- Electricity grid and power transfer equipment: These standards cover connection to the grid, EMC (electromagnetic compatibility), harmonics and safety standards.
- Communication: the communications protocols between power grid, vehicle, on road infrastructure and the back office.
- Interoperability
- Health & Safety

This section of the report focuses on power transfer standards for the electric vehicles, with a specific focus on dynamic solutions. There are at this time no published standards for dynamic power transfer solutions, although IEC 61980 aims to provide standardisation for inductive power transfer for EVs. The standards reviewed in this section are standards for automobile or electrical devices. The analysis of each standard include the description of the standard and test limits, For the sake of brevity test methods will not be included in this report; with that said, full standards are easily available on the publisher's website.

It should be noted that the standards stated in this report are those most specifically relevant to on road power transfer. It is not possible to describe all standards which may have a

bearing on EVs, power transfer, grid and communications as this would include many hundreds of standards.

2.2.1 IEC 61980- Electric Vehicle Wireless Power Transfer Systems

IEC 61980 was first prepared during the 1990s and reached the Committee Draft stage in 2000. Since 2013 the standards has been in a “circulated as committee draft with vote” phase. This draft standard consists of three parts:

- Part 1: General requirements for all inductive charging systems.
- Part 2: Requirements for communication between EV and infrastructure with respect to WPT systems.
- Part 3: Requirements for the magnetic field power

IEC 61980-1

Part 1 focuses on general requirements for wireless power transfer (WPT). The main areas covered in IEC 61980-1 are EMC, electrical safety, operational and functional characteristics and environmental testing.

IEC 61980-2

Part 2 focusses on specific requirements for communication between the EV and infrastructure with respect to WPT systems.

IEC 61980-3

Part 3 focuses on requirements for the magnetic field power transfer systems

2.2.2 IEC 61000 Electromagnetic Compatibility (EMC)

EMC is defined as "The ability of an equipment or system (or installation) to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment”. IEC standards are generically known as EMC standards, the requirements are grouped in six parts;

- Part 1: General: General considerations (introduction, fundamental principles) Definitions, terminology
- Part 2: Environment: Description of the environment, Classification of the environment, Compatibility levels.

- Part 3: Limits: Emission limits, Immunity limits (in so far as they do not fall under the responsibility of the product committees)
- Part 4: Testing and measurement techniques: Measurement techniques testing techniques.
- Part 5: Installation and mitigation guidelines: Installation guidelines Mitigation methods and devices
- Part 6: Generic standards.

IEC 61000 contains general EMC publications, IEC 61000-3-4 and IEC 61000-3-5 which specifies the limits on emission of harmonic currents and voltage for current level greater than 16 A per phase. IEC 61000 parts 6-3 is the generic standards for emission for residential; commercial and light-industrial environments.

The results of the tests can be defined using following criteria (IEC);

- Criteria A – Performance within specification limits
- Criteria B – Temporary degradation which is self-recoverable
- Criteria C – Temporary degradation which requires operator intervention
- Criteria D – Loss of function which is not recoverable

2.2.3 CISPR 12

This standard applies to the vehicles, boats and internal combustion engines. The standard is titled “Radio disturbance characteristics - Limits and methods of measurement for the protection of off board receivers”. The limits are designed to provide protection for transmission receivers in the frequency range of 30 MHz to 1000 MHz (IEC, 2010). However this standard does not apply to rail, tramways or trolley buses

2.2.4 CISPR 25

CISPR 25 covers vehicles, boats and internal combustion engines. The standard aims to regulate the radio disturbance characteristics for the protection of on-board receivers. CISPR 25 covers limits and procedures for the measurement of radio disturbances in the frequency range of 150 kHz to 1000 MHz. The test is carried out on a complete vehicle. Disturbance limits are given in Table 1, these limits are recommendations; the manufacturer and component supplier can agree on modifications.

Table 1: Disturbance limits (Table from CISPR 25 Guideline)

Service/Band [b]	Frequency MHz	Terminal disturbance voltage at receiver antenna terminal dB(µV)				
		Broadband continuous		Broadband short duration		Narrowband
		Quasi-peak	Peak	Quasi-peak	Peak	Peak
Broadcast						
LW	0,15 to 0,30	9	22	15	28	6
MW	0,53 to 2,0	6	19	15	28	0
SW	5,9 to 6,2	6	19	6	19	0
VHF	76 to 108	6(15 [a])	28	15	28	6
Mobile services						
VHF	30 to 54	6(15 [a])	28	15	28	0
VHF	68 to 87	6(15 [a])	28	15	28	0
VHF	142 to175	6(15 [a])	28	15	28	0
UHF	380 to 512	6(15 [a])	28	15	28	0
UHF	820 to 960	6(15 [a])	28	15	28	0

[a] Limit for ignition systems only.

[b] LW: Long wave, MW: Medium wave, SW: Short wave (amplitude modulation, AM)
VHF: Very high frequency, UHF: Ultra high frequency (frequency modulation, FM)

NOTE 1 All broadband values listed in this table are valid for the bandwidths specified in table 3.

NOTE 2 Stereo signals may be more susceptible to disturbance than monaural signals in the FM broadcast band. This phenomenon has been factored into the VHF (76 MHz to 108 MHz) limit.

NOTE 3 When possible it may be advisable to switch broadband only disturbance sources off for the measurement of narrowband disturbance.

2.2.5 ICNIRP

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an international organisation which aims to protect against adverse health effects by determining exposure limits of Electromagnetic waves from electronic devices. ICNIRP has published EM exposure guidelines in 2010. This document was titled; “ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300GHz).” Table 2 shows the magnetic and electric field exposure limits for specific frequencies. The operational frequency range for most current resonant chargers is between 2 and 15kHz therefore as seen from Table 2 the magnetic field limit in this band is 6.25uT and electric field strength limit is specified at 87 V/m

Table 2: Reference levels for public exposure (Diagram: ICNIRP)

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	4,000/f	5,000/f	—
0.025–0.8 kHz	250/f	4/f	5/f	—
0.8–3 kHz	250/f	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	0.73/f	0.92/f	—
1–10 MHz	$87/f^{1/2}$	0.73/f	0.92/f	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	f/200
2–300 GHz	61	0.16	0.20	10

[a] Note:
1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

2.2.6 ISO 16750

ISO 16750 is titled as “Road vehicles — Environmental conditions and testing for electrical and electronic equipment”. This standard applies to electrical and electronic systems and components of the road vehicle; the standard consists of 5 parts;

- Part 1: General
- Part 2: Electrical Loads
- Part 3: Mechanical Loads
- Part 4: Climatic Loads
- Part 5: Chemical Loads

2.2.7 ISO 26262

ISO 26262 is a functional safety standard for road vehicles which addresses potential failures in electrical and electronic systems and develops a structure for hazard elimination (ISO, 2014). ISO 26262 include 10 sections with approximately 750 clauses and covers the life of the system from design to decommissioning.

2.2.8 ISO 6469

ISO 6469 contains safety specifications for electrically propelled road vehicles and consists of three parts;

- ISO 6469-1:2009; electrically propelled road vehicles, Safety specifications Part 1: On-board rechargeable energy storage system, This standard is applicable for voltages up to 1000V AC or 1500VDC.
- ISO 6469-2:2009; electrically propelled road vehicles, Safety specifications Part 2: Vehicle operational safety means and protection against failures. The standard include procedures such as;
    - The vehicle must be switched off when power transfer
    - Operational indications to the drivers such as displaying low SOC.
    - Deceleration should be same as ICE engine vehicle when the gas pedal is released.
    - Maximum reverse speed must be limited
    - Protection of auxiliary systems against over voltage.
    - Over-current cut-off
- ISO 6469-3:2011; Electrically propelled road vehicles, Safety specifications Part 3: Protection of persons against electric shock
    - Class I equipment, where protection against electric shock is ensured by equipotential connection of exposed live parts using a protective conductor.
    - Class II equipment, where protection against electric shock is ensured by using double insulation or reinforced insulation.
    - Minimum insulation
    - Resistance, being 1000 Ω/V for class I equipment and 5000 Ω/V for class II equipment. (ISO, 2009)

2.2.9 ISO 15118

This Standard is titled “Road Vehicles – vehicle to grid communication interface” and specifies the communication between Electric Vehicles (EV) and power supply equipment. This standard consists of three parts;

- Part 1: General information and use case
- Part 2: Network and application protocol requirements
- Part 3: Physical and data link requirements

2.2.10 ISO 11451

The ISO 11451 series of standards relate test methods for evaluating automotive EMC issues. Relevant standards within this series include:

- **ISO 11451-1:** Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 1: General and definitions
- **ISO 11451-2:** Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 2: Off-vehicle radiation source
- **ISO 11451-3**: Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 3: On-board transmitter simulation
- **ISO 11451-4**: Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy - Part 4: Bulk current injection (BCI)

A related relevant standard is **ISO 11452:** Road vehicles - Electrical disturbances by narrowband radiated electromagnetic energy - Component test methods

2.2.11 SAE J2954

The draft SAE J2954 guideline aims to establish minimum performance and safety criteria for wireless charging of electric and plug-in vehicles. SAE J2954 also focuses on standardising the interface to improve interoperability and develop procedures for subsystems to communicate. The topics for SAE J2954 are:

- Testing
- Minimum efficiency
- Positioning of the vehicle and charging unit
- Potential locations for Residential and on road charging
- Frequency
- Communications and Software
- Interoperability
- Safety (magnetic field, charging SOC, temperature, shock, charging level)

(Schneider, 2012)

2.3 Patents

The purpose of this section is to analyse the patent applications relevant to wireless energy transfer. The analysis identifies;

- Application dates,
- Contents of the patent
- Organisations that own the patents
- General trends in patent applications.

2.3.1 Patent protection

A patent protects the new inventions to promote innovation and give the inventor comparative advantage for limited amount of time, generally up to 20 years. For an invention to be eligible for a patent it;

- Must be a new invention
- Must have inventive steps
- Must be capable of been made and used in an industry

An invention can be a new product, process or a solution to a technical problem. For an invention to be patented it must not be a mathematical or a scientific discovery, a theory or a method.

2.3.2 Power Transfer Patents

The power transfer patents reviewed are in general based on wireless power transfer. The study include patents are from dynamic power transfer systems such as KAIST, as well as static power transfer solution such as WiTricity, University of Auckland or Conductix Wampfler. The patents in dynamic energy transfer can be divided into three areas:

- Energy transfer solution and control systems (power transfer control, device alignment, object detection)
- Communication
- Protection (electronic protection devices, equipment cooling and EMF/EMI minimisation or cancellation)

The organisations that have developed power transfer solutions have filed a large number of patents; for example KAIST has filed over 170 patents for their online electric vehicle. The organisations which have filed the greatest number of patents are KAIST, QUALCOMM, WiTricity, University of Auckland and Conductix Wampfler. As shown in Figure 5 patents are mainly based in US, South Korea, China, New Zealand and Germany. It should be noted that same patent application can be filed in number of countries,

Figure 6 shows the patent applications by year. As shown, between 1993 and 2008, there have been over 500 applications. The patent applications started to increase after 2008 and rose dramatically in 2011. The rate of applications is expected to remain high for the foreseeable future.

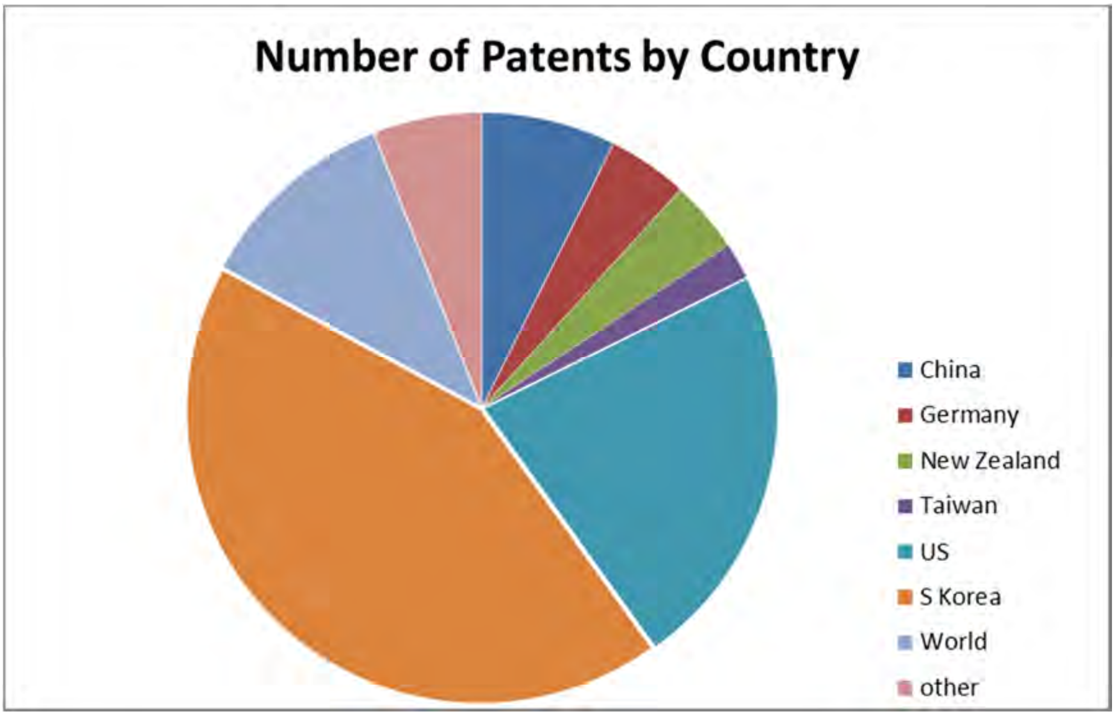

Figure 5: Number of Patents by Country

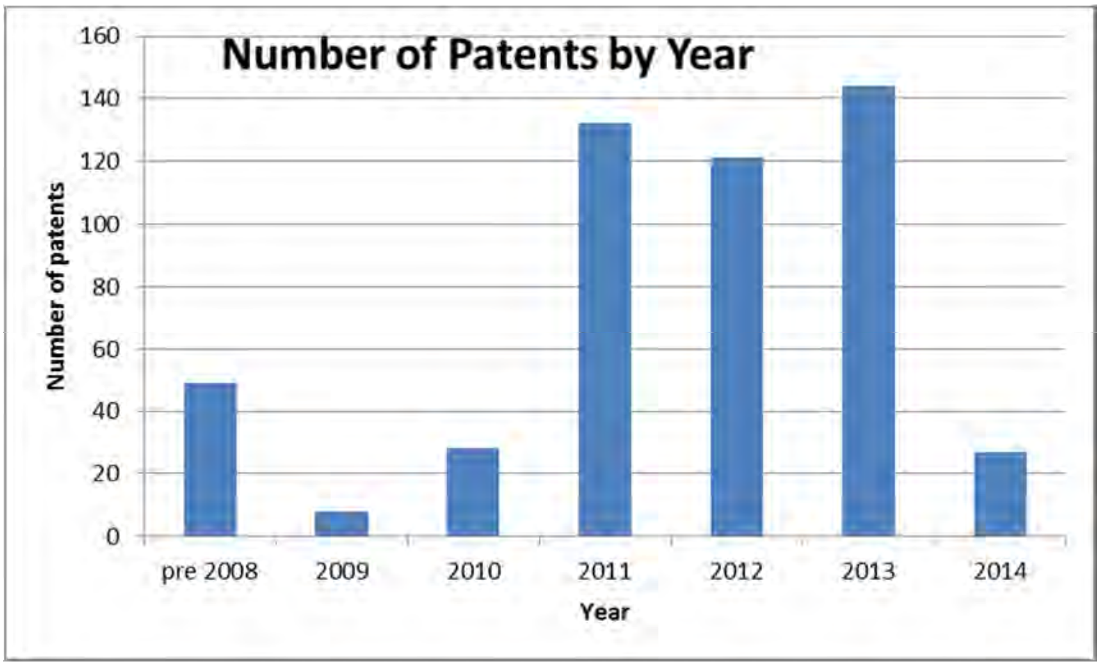

Figure 6: Number of Patents by Year

3 STATE OF THE ART - COMMUNICATIONS

This chapter reviews the state of the art in communications technologies for on-road power transfer. While communications systems are not technically part of a power transfer system, they are essential for any practical implementation of an on-road dynamic charging system, both for control and for billing purposes. As this section is self-contained, it can be ignored by those readers who have no interest in the communications aspects of FABRIC.

In the first part of the document a preliminary architecture of the system is defined in order to identify the main communication channels required. This architecture is by no means final and it will be updated in WP24 after the functionalities of the system and its boundaries are defined in WP22.

Based on the foreseen communications needs, the relevant existing standards are listed and a preliminary mapping of communication standards to communication needs is performed.

Section 3.1 describes the preliminary communications architecture envisaged for FABRIC. Sections 3.2 and 3.3 describe current wired and wireless communications technologies which are then evaluated for suitability in FABRIC in sections 3.4 to 3.6.

3.1 FABRIC preliminary communications architecture

In Figure 7, the preliminary concept of FABRIC, as described in the Description of Work, is sketched.

According to this preliminary concept the following functionalities can be identified:

- Charging request to the infrastructure by the EV
- Approval/denial of request
- Automatic detection of vehicle and identification of driver by road side unit (RSU) connected to the wireless charging modules
- Driver assistance services provided by the infrastructure, regarding speed, alignment/lane departure
- Traffic control services provided by the infrastructure
- V2V (Vehicle to Vehicle) communication
- Charging status measurement and payment information provided by the infrastructure to the vehicle and/or driver

- Energy management by the grid operator based on requested charge and the grid status

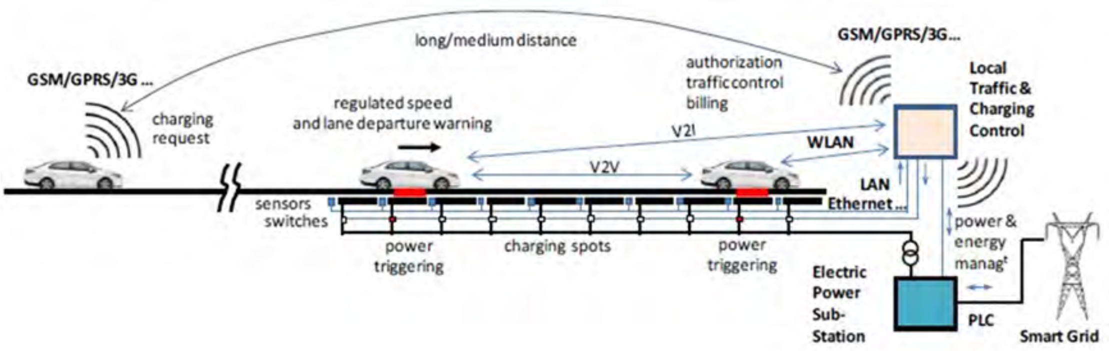

Figure 7: Schematic principle of the FABRIC ICT solutions related to the operation of an on-road-charging station. Several communication channels are depicted.

Based on the identified preliminary functionalities several long and short-range communications, both wireless and wired can be identified.

Specifically the following communication modes should be included:

- Vehicle to infrastructure (road authority) long-range communication (wireless)
- Vehicle to Infrastructure (grid authority) long-range communication (wireless)
- Vehicle to Infrastructure (RSU) short-range communications (wireless)
- Vehicle to Vehicle short-range communications (wireless)
- Grid operator to energy supplier communication (wired)
- RSU (metering/control) to grid operator (wired)
- Infrastructure to driver HMI (mobile phone or other)

Figure 8 provides a close up to the wireless charging concept that will be used in the Satory test site which will implement the QUALCOMM system. In this figure we can see in more detail the infrastructure-side communications needed when the vehicle is in charging mode:

- Vehicle/driver identification
- Vehicle position detection so as to energize a specific charging pad
- RSU communication with grid (Backbone) infrastructure

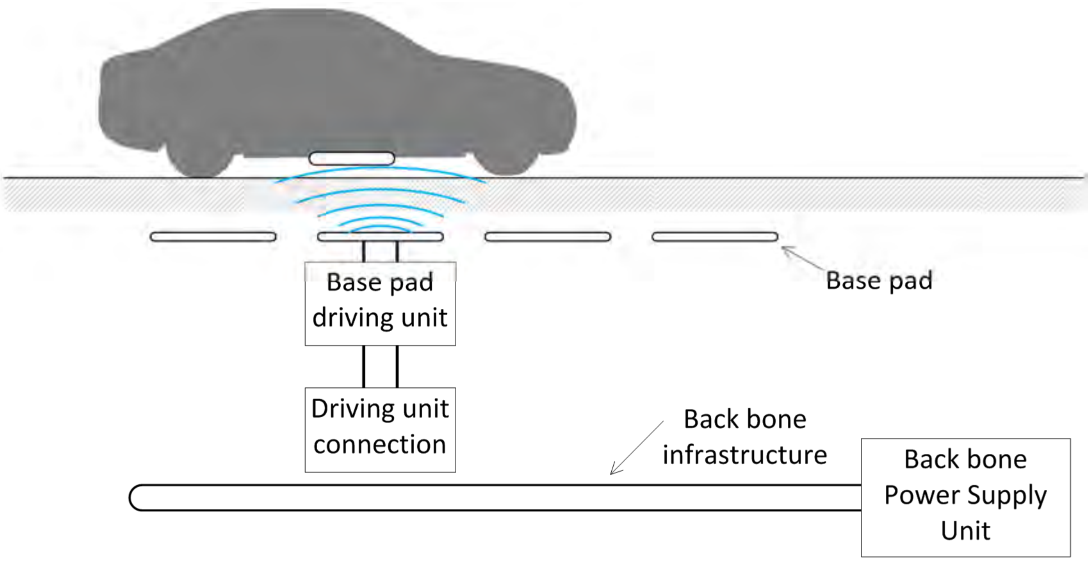

Figure 8: Draft concept of an installed QUALCOMM system for wireless dynamic charging

In Figure: 9 a preliminary topology of the installed pads and their connection to the grid is depicted.

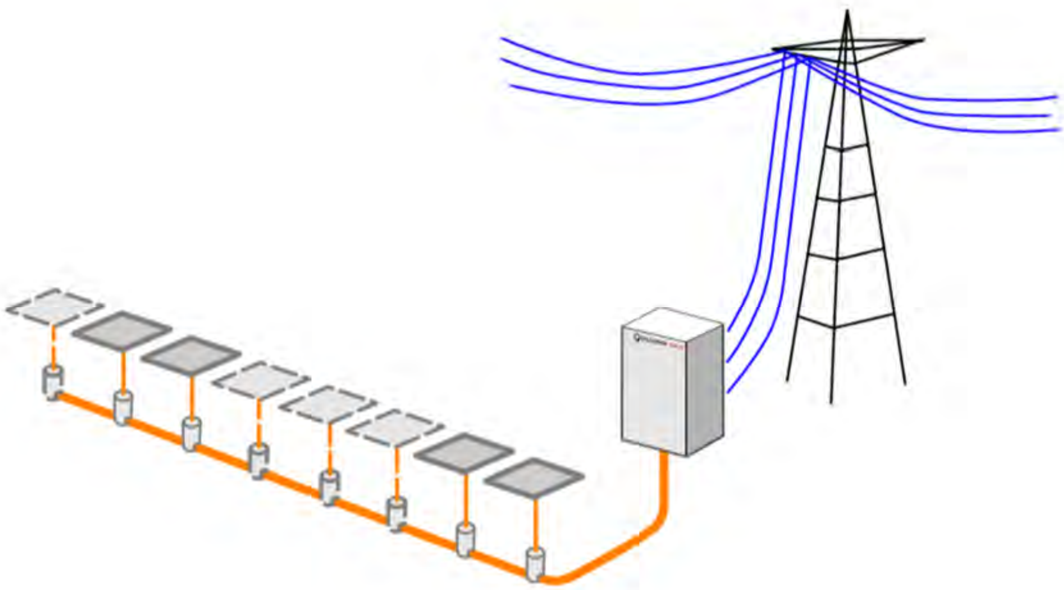

Figure: 9: Topology concept of QUALCOMM system to be installed in Satory test site. Wired communication channels are evident.

Table 3 provides a mapping of communication modes to FABRIC functionalities.

Table 3: Communication Modes

Communication mode	Example Functions
V2I (vehicle to infrastructure) (road authority) long-range communication	Charging request to the infrastructure by the EV Approval/denial of request Information about available charging lanes and directions on how to reach them
V2G (vehicle to grid((grid authority) long-range communication	
V2I medium/short-range communications	Automatic detection of vehicle and identification of driver by RSU connected to the wireless charging modules Driver assistance services provided by the infrastructure, regarding speed, coil alignment/lane departure Traffic and charging control services provided by the infrastructure
V2V (vehicle to vehicle) short-range communications	Traffic report/control services provided by other vehicles
Grid operator to energy supplier communication	Energy management by the grid operator based on requested charge and the grid status. Energy tariff information.
RSU to grid operator	Automatic detection of vehicle and identification of driver Charging status measurement
Infrastructure to driver HMI (Human Machine Interface)	Payment information

In the following section, the available solutions and standards for the realization of these communications are presented in detail.

3.2 Wired Technologies

This section reviews the wired technologies such as narrowband, broadband and DSL. Each technology is reviewed on coverage, data transfer rate, operation frequencies and latency.

3.2.1 Narrowband Power line Technologies

These are technologies intended to transfer a relatively low data rate over the power line infrastructure, normally used in control applications. The most important characteristics are shown in the table below.

Table 4: Narrowband PLC Technologies (Source: Texas Instruments, Smart Grid Business Unit, (Smart grid, 2011)

Parameter	IEC61334 S-FSK	PRIME (OFDM)	G3 (OFDM)	P1901.2 (OFDM)
Modulation Size	Spread Frequency Shift Keying	DBPSK/DQPSK /D8PSK	DBPSK/DQPSK (D8PSK)	DBPSK/DQPSK/D 8PSK Coherent Modulation
Forward Error Correction	N/A	Rate ½ Convolutional Code	Outer RS + inner rate ½ convolutional code	Outer RS + inner rate ½ convolutional code
Data Rate	2.4 kbps	21, 42, 64, 84, 64 kbps (w/ coding)	20.36,/34.76/ (46) kbps (with coding)	Scalable up to 250 kbps
Band plan	CENELEC-A	Continuous 42-89 kHz (defined for LV scenario)	36-91 kHz with tone masking for SFSK	CENELEC-A, FCC band
ROBO Mode	No	No	Yes	Yes
Tone Mask	No	No	Yes	Yes
Adaptive Tone Map	No	Yes	Yes	Yes
MAC	IEC61334 MAC	PRIME MAC	802.15.4/G3 profile	802.15.4 based
Convergence Layer	IEC61334-4-32	IEC61334-4-32/IPv4	6LoWPAN/IPv6	6LoWPAN/IPv6
Meter Application	COSEM/DLMS	COSEM/DLMS, IP	COSEM/DLMS, IP	COSEM/DLMS, IP
Application	Meter reading, home automation, controlling (load control, remote control), demand response applications			

3.2.2 Broadband Powerline Technologies

These are technologies intended to transfer high data rates over the power line infrastructure. They are principally used to implement networking infrastructure over power lines, mostly within buildings.

Table 5: Broadband PLC Technologies

Technology	Organization	Technical Issues	Application
ITU G.hn (G.9960/G.9961)	ITU, Home Grid Forum	2-30 MHz, 50-305 MHz Up to 1 Gbps OFDM based (up to 4096-QAM)	Multiple media BB networking and entertainment
ITU G.hn LCP (G.9960/G.9961)	ITU	Wired media: power line, coax, phone line Reduced complexity and power consumption 2-25 MHz, 5-20 Mbps QPSK only, AES-128 Low latency	Smart Grid EV charging Home Automation
IEEE1901	IEEE	2-68 MHz Up to 500 Mbps Defines PHY and MAC Coverage 100 m (in-house), 1500 m (access)	Similar to HomePlug AV2, HD-PLC, ISP with additional features Use of 30-50MHz is optional
Home Plug AV	HomePlug (industry)	2-28 MHz Up to 200 Mbps (4-10 Mbps ROBO mode) OFDM based (xPSK, xQAM)	Multiple media BB networking and entertainment
Home Plug AV2	HomePlug (industry)	2-68 MHz Up to 500 Mbps (150 Mbps is more realistic) (Gigle Chip up to 305 MHz) OFDM based (up to 4096-QAM) Support of MIMO PHY	HD/3D streams Next-generation broadband

HomePlug GreenPHY (Profile of P1901)	HomePlug (recommended for ISO 15118)	Stripped down version of HomePlug AV Up to 75% lower costs and less power consumption than HP AV Interoperable with HP AV and P1901 2-30 MHz Up to 10 Mbps	Smart Grid V2G applications Demand response Load control Home/Building Automation

3.2.3 DSL Technologies

These are technologies used to connect homes and businesses to the national data infrastructure.

Table 6: DSL Technologies

Technology	Max. Rate DS	Max. Rate US	Coverage	Modulation	Application
SHDSL	5,6 Mbit/s	5,6 Mbit/s	3 - 9 km	TC-PAM	Wide range of applications in the private and business area: - Triple Play - Voice over DSL - Video-Conference - HDTV - Gaming - E-Commerce
ADSL	7 Mbit/s	800 Kbps	5.3 km (DS 768 kbps)	DMT	
ADSL2	8 Mbit/s	1 Mbit/s	5.5 km	DMT	
ADSL2+	24 Mbit/s (up to 1.2 km)	1 Mbit/s	5.5 km	DMT	
ADSL2 RE	8 Mbit/s	1 Mbit/s	5.8 km (DS 768 Kbps)	DMT	
VDSL2	55 Mbit/s 100 Mbit/s	30 Mbit/s 100 Mbit/s	Long Reach (12 MHz) < 1 km Short Reach (30 MHz) < 0.3 km	DMT	

3.3 Wireless Technologies

This section is the review of wireless communication technologies such as mobile communications, local radio and WPAN based communications. The review of each technology includes, operational frequency range, data transfer rate, bandwidth, latency and active operation range.

3.3.1 Mobile Communication Technologies

Table 7: 2G/3G/4G Technologies (Telefónica O2, UMTS Forum, 2010)

Technology	UL Peak Data Rate	DL Peak Data Rate	Latency	Carrier BW	Spectrum [MHz]	Peak Spectral Eff. (Bit/s/Hz)
GSM / GPRS **EDGE (MCS-9)**	56 kbps 118 kbps	114 Kbps 236 Kbps	500 ms 300 ms	200 kHz	900/1800	0.17 0.33 EDGE
W-CDMA	384 kbps	384 Kbps (2 Mbps)	250 ms	5 MHz	900/1800/ 2100/2600	0,51
HSPA	5.7 Mbps	14 Mbps	~ 70 ms	5 MHz	DD/900/ 2100/2600	2,88
HSPA+ (16 QAM) **(64 QAM + Dual)**	11.5 Mbps	~28 Mbps (42 Mbps)	~ 30 ms	5 MHz	DD/900/ 2100/2600	12,5
LTE (Rel.8) **(2x2 MIMO)**	~75 Mbps	~150 Mbps @20 MHz	~ 10 ms	var. up to 20 MHz	DD/900/1800/ 2100/2600	16,32
WiMax **IEEE 802.16e**	70 Mbps	70 Mbps 134 Mbps	~ 50 ms	10 MHz	2600/3500	3,7
LTE Advanced	>500 Mbps	>1 Gbps	< 5 ms	var. up to 100 MHz	IMT	DL: >30 UL: >15

IMT Advanced	270 Mbps 675 Mbps	600 Mbps 1,5 Gbps	< 10 ms	var. up to 100 MHz	IMT	DL: >15 UL: >6.75

3.3.2 Local Radio Technologies

Table 8: Local Radio Transmission Technologies

	UWB	**WLAN**	**Bluetooth**
Main Application	Wireless alternative to USB	Local radio networks for access purposes (e.g. office environment)	Radio transmission over short distance (e.g. headset)
Frequency	3,1-10,6 GHz	11a: 5 GHz 11b/g: 2,4 GHz 11n: 2,4 and/or 5 GHz 11p: licensed ITS band of 5.9 GHz (5.85-5.925 GHz)	2,4 GHz
Transmission Technique	WiMedia: OFDM	11a/g: OFDM 11b: DQPSK + DSSS 11n: OFDM 11p: OFDM	v1.x: GFSK + FHSS v2.x: DQPSK / 8DPSK + FHSS v3: +WLAN channel
Data Rate	WiMedia: 480 Mbps	11a/g: 54 Mbps 11b: 11 Mbps 11n: < 600 Mbps 802.11p: 3-27 Mbps	v1.x: 1 Mbps v2.x: 3 Mbps V3: 24 Mbps
Coverage	10 m	30-150+ m	10-100+ m
Channel Access	WiMedia:CSMA/CA	DCF: CSMA/CA PCF: Polling HCF: QoS extension DCF: CSMA/CA	Polling, TDD

3.3.3 WPAN based Technologies

Table 9: IEEE802.15.4 based Technologies

	Technical Specs	Features	Issues
ZigBee	250 kbps (20/40 kbps) 10 - 100 m	Support of Sleep Modes Multi-hop communications ZigBee Smart Energy Profile and Certification	Vulnerable to replay attacks (security) Restricted access to the stack
6loWPAN	20 kbps 10 - 100 m	IPv6 (easy integration into existing networks and connecting other devices) Freely available	Interoperability cannot be guaranteed due to a lack of certification 6loWPAN doesn't have a real market
wM-Bus	TX: 66,66 kbps RX: 16,38 kbps 30 - 50 m	Uni-and bi-directional operation possible Partly compatible with KNX-RF Freely available	
KNX-RF	20 kbps 30 m	Partly compatible with wM-Bus Already built-in applications such as heating or cooling	

3.4 Communication technologies for ITS: V2X and LTE

Long and short-range communications in Intelligent Transport Systems (ITS) play a central role for the deployment of related applications and services. These applications and services embedded in a mobility context establish very stringent requirements regarding diverse aspects of safety, reliability and security, among others, which due to the very dynamic environment and usage context pose high demands on the underlying communication technologies. In general, the employed technologies must offer flexible adaptive coverage from several meters to several thousand meters, they must support environments shared by multiple overlapping wireless networks, and must offer real-time and non-real-time reliable unicast, multicast, broadcast and geocast data distribution. Further, ITS environments are characterized by a large number of heterogeneous participants, thus yielding the following communication relationships: Vehicle-To-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P) and Pedestrian-to-Pedestrian (P2P). These vehicular communication relationships are generically referred to as V2X. In addition and within the context of FABRIC project Vehicle-to-Grid (V2G) relationship is also essential.

Heterogeneous actors need to be supported by proper infrastructure, spanning a wide range of hardware devices, each with their particular technological requirements regarding communications, power consumption and processing power: Roadside Units (RSU) for the fixed traffic and charging infrastructure, On-board Units (OBU) for vehicles and smartphones for drivers. For this reason, there is a clear need for hybrid networks comprising mobile (2G, 3G, 4G) and short-range ad-hoc networks, like ETSI ITS-G5 (ETSI). Long Term Evolution (LTE) shows in this regard the potential to cover many of the above V2X needs depending on the particular use case, however coverage and compatibility to existing and future ITS technologies will be decisive for acceptance and widespread use of it.

FABRIC will employ, adapt if needed, and combine some of the available technologies in order to cope with challenges presented by dynamic charging of FEV. The project concentrates basically on future-oriented technologies dealing with long-range (LTE) and short-range (IEEE 802.11p) (IEEE 802.11p, 2014) communications, potentially combined with standards and protocols like GeoNetworking (ETSI, 2011), CALM and IEEE 1609 (IEEE, 2014), among others. In addition wired DSL-based technologies and communications over power lines will be implemented to achieve low communication latency. This document serves only as a preliminary identification of the communication interfaces and a SotA on communication technologies that may be suitable for each interface. The final

communication interfaces and technologies that will be selected will be defined in detail in FABRIC WP2.

3.4.1 State of the art

FABRIC applications will be based on both short-range (local-area) and long-range (wide-area) wired and wireless communication technologies. The most prominent representative of short-range wireless communications are vehicular ad-hoc networks, like ETSI ITS-G5 based on IEEE 802.11p. These technologies may be used also for short-range V2I communication. For long-range communications, cellular networks such as 2G, 3G and LTE are potential candidates. Previous research projects such as GeoNet, PRE-DRIVE C2X (Pre-drive C2X), SAFESPOT (Safetspot), and CVIS (CVIS Project) have developed and demonstrated ETSI ITS-G5 and ETSI GeoNetworking technologies for vehicular applications. In 2008, the EC allocated dedicated frequencies (5875–5905 MHz) for traffic safety and efficiency applications. The ongoing European project DRIVE C2X is about to conduct field operational tests (FOTs) to validate the technology under real-world conditions. National FOTs like simTD (Simtd) in Germany are contributing to this European effort. Preliminary experimental data indicates that short-range technologies such as 802.11p and GeoNetworking are now mature and allow vehicles to exchange data within a small distance (1-2 km) in real-time (10-100 ms). The low latency of such technologies may allow their use for short range V2I communication within FABRIC.

Even though it remains challenging to employ these technologies for large geographic areas, e.g. tens of square kilometres, FABRIC is not foreseen to need very long range real time V2V or V2I communication. 2G and 3G cellular networks provide long-range communication and have been evaluated in research projects such as PRE-DRIVE C2X and simTD. The general conclusion was that these technologies were not able to meet all stringent requirements for latency of ITS applications. Furthermore, ITS applications using 2G and 3G technologies also face challenges regarding bandwidth requirements and scalability. However, these limitations will likely change when LTE (Long Term Evolution) will be deployed.

Long-Term Evolution (LTE)

Key technical characteristics of LTE: Several operators have named this '4G', but this is more of a marketing strategy then truth. ITU classifies LTE as an evolution of IMT-2000 and hence it belongs to the 3G categorisation of protocols like WCDMA and HSPA.

There are two major characteristics that make LTE important. First, it will deliver data-rates higher that 20Mbps. TeliaSonera (Teliasonera) launched an LTE based network in Sweden at the beginning of 2010 and has reported average rates of 25Mbps, whereas peek rates exceed 50Mbps. Moreover, LTE is expected to be adopted internationally by more than 200 operators.

Two variants of LTE technology exist, namely FDD (Frequency Division Duplex) and TDD (Time Division Duplex). The latter is being deployed in the 2.5GHz spectrum band. The deployment of TDD-LTE will be affected mainly by its adoption from the Chinese and Indian telecom market. Nowadays, multi-mode FDD/TDD chipsets are supported by manufacturers to facilitate interoperability and regional roaming functionality (Connecting Cars: The Technology Roadmap, 2014)

Coverage: LTE coverage today is low, both in terms of market adoption, and coverage offered within the markets that have launched it (approximately 100 LTE networks commercially deployed to date, covering almost 5% of global population - mainly large cities). LTE deployment partially depends on the availability of 'digital dividend' spectrum, which is in low frequency bands, and hence is suitable for good rural coverage. However, LTE at the moment is still in its infancy and network build-out is slow and relatively expensive. It is estimated that LTE deployment will likely follow the same pattern as 2G and 3G service roll out, with growing economies for suppliers of network equipment, device components and LTE based applications, driven by increasing scale and adoption. As LTE scale grows, costs fall, thus making LTE accessible to a growing customer base; The expected coverage of LTE in 5 years is 10% (Connecting Cars: The Technology Roadmap, 2014). Many ITS applications require complete coverage in order to be deployed and some analysts expect 100% coverage by 2015.

Bandwidth and Latency: The theoretical maximum download rate of LTE is 170Mbps and initial network deployments deliver data at a rate between 10Mbps and 50Mbps. Generally speaking these rates are higher than current consumer fixed line rates using DSL and cable modem technologies as well as wireless 3G HSDPA/HSUPA.

LTE has been designed for low latency from its inception. It was designed with a requirement for less that 10ms latency, which makes it an ideal technology for voice services and video telephony. However latencies of up to 50ms could be experienced in real networks. Moreover the LTE standard uses the IP Multimedia Subsystem (IMS) to deliver voice, instead of using circuit-switched technology.

A complete assessment of the operating metrics of LTE was performed by the LTE/SAE Trial Initiative (LSTI) (3gpp standardisation body, 2010). The initiative was founded in May 2007, and was driven by vendors and operators. LSTI co-ordinated industry wise interoperability tests, in which various vendors and operators participated. Moreover LSTI held live demonstrations in real conditions thus showing LTE maturity in 2009. In January 2011, LSTI concluded its work and presented its results at the Mobile World Congress 2011.

LSTI trials confirm that in ideal radio conditions round trip times on 32Byte messages fall below 15ms; these performances are aligned with measurements published by other sources such as the EASY-C research project (reporting some measurements below 10ms). The priority of V2X related applications and services regarding round trip delay, e.g. a guaranteed QoS, needs to be debated.

LSTI registered measurements have met or at times exceeded 100 Mbps for downlink and 30-50 Mbps for uplink in both FDD and TDD systems. Cell Capacity has been estimated to reach an average value equal to 40 Mbps on 20 MHz channels even in realistic interference conditions (NGNM, 2011).

Spectrum Consideration: Two ‘digital dividend’ primary spectrum bands for LTE are placed at 700MHz or 800MHz (dependent upon market) and the IMT-extension band (2.5-2.6GHz). Digital dividend spectrum is being freed by the move from analogue to digital broadcast signals for television. Since transition from analogue to digital is ongoing in markets around the world, the availability of this band varies across markets. The 2.6GHz band is open in markets and as such it has a good degree of alignment in licensing, notably in Europe. This spectrum is also being licensed around the world at the moment with varying timelines.

More than 10 spectrum bands have been defined by ITU-R (ITU Radiocommunication Sector). but they are not globally harmonized

Figure 10: Worldwide LTE spectrum availability (Connecting Cars: The Technology Roadmap, 2014)

Vehicular Communication Systems

V2X Vehicular Communication Systems mainly consist of vehicles and roadside units that exchange information, such as safety warnings and traffic status. Applications like collision avoidance and congestion reduction have been developed to exploit V2X network capabilities. Moreover many higher layer protocols are being developed in order to introduce novel electro mobility services based on V2X communications. An example of such a protocol is the electric vehicle charging spot notification specification which provides EV drivers with updated information about charging stations and spots. (ETSI TS 101 556-1, 2012)

Two types of nodes are most popular in vehicular networks: vehicles and roadside stations. Communications-wise they can be developed/ implemented as Dedicated Short Range Communications. DSRC uses the 5.9GHz band with a bandwidth of 75 MHz and an approximate range of 1km. The network supports private and public data transfer, with higher priority given to safety related data exchange. In addition to DSRC, wired communications

are also used in order to interconnect Road Side Units with ITS application enabling infrastructure.

Motivation

Safety and collision cost elimination where initially the main objectives that drove vehicular communication systems development. According to the World Health Organization (WHO), road accidents annually cause approximately 1.2 million deaths worldwide; one fourth of all deaths caused by injury. In addition 50 million people are injured in traffic accidents. Unless preventive measures are taken, road death is likely to become the third-leading cause of death in 2020 from ninth place in 1990.

However the deaths caused by car crashes are in principle avoidable. The US Department of Transport states that 21,000 of the annual 43,000 road accident deaths in the US are caused by roadway departures and intersection-related incidents. Deployment of local warning systems based on vehicular communications can minimize such incidents. Vehicles that depart an intersection or cross an intersection can send cooperative awareness messages (CAM) to warn nearby vehicles. Studies show that in Western Europe a mere 5 km/h decrease in average vehicle speeds could result in 25% decrease in deaths. Moreover speed limit enforcement will be notably easier and more efficient using communication technologies.

Although the main objective of vehicular communications is overall safety improvement, there are several other benefits. Vehicular networks enhance applications like congestion reduction and route navigation by enabling real time data processing.

V2X communications will bring added value services to FABRIC in a twofold manner. Firstly traffic management applied to road segments prior to charging lanes will be applied in order to reduce traffic congestion. In addition, traffic accidents can be reported on time to avoid incident escalation. On time reports on traffic and charging lane availability may allow efficient re-routing to other charging lanes or fixed charging infrastructure.

The second way which is foreseen in the document “FABRIC experience” that contains preliminary generic scenarios of use for the FABRIC concept, allows real time dynamic charging management by prioritizing the vehicles according to their needs and other criteria. This scenario includes real time negotiation of charging lane usage between vehicles that have different priority index. This negotiation can be done either between vehicles or via a

control centre (V2I communication). In both cases V2V communication is necessary to warn other vehicles about the potential changes in the charging lane queue.

Development

Several ITS institutions aim at bringing ITS concepts to the real world. Among them the U.S. Department of Transportation (US DoT), promotes ITS through investment in potentially high payoff initiatives. The Vehicle Infrastructure Integration (VII) initiative, aims at increasing safety by providing vehicle to vehicle and vehicle to roadside units communications through Dedicated Short Range Communications (DSRC).

The Intelligent Transportation Society of America (ITSA), which encompasses a diverse set of stakeholders including private companies, universities, and government agencies, aims at improving cooperation among public and private sector organizations regarding ITS related topics. Its mission statement is to reduce fatal accidents and delays as much as possible.

Among the research institutions and universities that are active in vehicular and ad hoc networks, University of California, Berkeley, Stanford, UCLA, MIT, Texas A&M are only some of the North American institutes that participate in ITS related bodies such as the Partnership for Advanced Transit and Highways. (PATH)

Car manufacturers and OEMs that are very active in vehicular communications include among others: BMW, Ford Motor Company, General Motors, Honda, Kapsch, Mercedes-Benz, Siemens, Toyota.

Moreover automobile manufacturers like GM offer integrated automobile devices like OnStar. Such systems allow third party service integration such as route navigation and emergency assistance.

Technical specifications

Two categories of draft standards provide outlines for vehicular networks. 802.11p, also known as Wireless Access in Vehicular Environments (WAVE) is an extension to the 802.11 Wireless LAN medium access layer (MAC) and physical layer (PHY) specification. The 2012 IEEE 802.11 standard revision has included the 11p amendment directly into the Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. IEEE 1609 is a

family of standards that addresses issues such as management, security and multi-channel operation of the network on top of IEEE 802.11p. It consists of the following standards:

1609.1 - Resource Manager: This standard provides a resource manager for WAVE, allowing communication between remote applications and vehicles.

1609.2 - Security Services for Applications and Management Messages.

1609.3 - Networking Services: This standard addresses network layer issues in WAVE.

1609.4 - Multi-channel Operation: This standard deals with communications through multiple channels.

The current state of these standards is trial-use. The main nodes of a vehicular communication network using these standards are On Board Units (OBU) and Road Side Units (RSU). RSUs are very much like wireless LAN access points and they offer a communication link with the infrastructure. Also, if required, RSU must be able to allocate channels to OBUs. In addition to the previous communication nodes a third one called Public Safety OBU (PSOBU) exists. PSOBUs are installed in vehicles and have capabilities of providing services normally offered by RSU. These units are mainly utilized in police cars, fire trucks, and ambulances in emergency situations.

DSRC provides seven 10 MHz channels in North America for communications. These channels are divided into one control channel and six service channels. The control channel is reserved for broadcasting and coordinating communications which take place in the service channels. DSRC devices sense both control and service channels. There is no scanning and association as it is in normal 802.11. Such operations are done via a beacon sent by RSUs in the control channel. While OBUs and RSUs are allowed to broadcast messages in the control channels, only RSUs can send beacon messages.

Among service channels, 2 of them are used only for high priority messaging, thus providing a framework for public safety application enhancement.

In summary 802.11p and 1609 drafts, specify baselines for vehicular networks development. However many issues are not addressed yet and research is going.

802.11p (IEEE 802.11p, 2014) IEEE 802.11p is an amendment to the IEEE 802.11 standard, oriented towards Wireless Access in Vehicular Environments (WAVE). It defines enhancements to 802.11 (the basis of products marketed as Wi-Fi) required to support

Intelligent Transportation Systems (ITS) applications. Such enhancements include requirements for communication between high-speed vehicles and roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). IEEE 1609 is a higher layer standard based on the IEEE 802.11p.

802.11p is used as a base for the Dedicated Short Range Communications (DSRC) project driven by the US Department of Transportations which is based on the ISO Communications, Air-interface, Long and Medium range (CALM) architecture, dealing with vehicle-based communication networks, particularly for applications such as safety, toll collection, and in vehicle e-commerce transactions. The ultimate vision is a nationwide network that enables communications between vehicles and roadside access points or other vehicles. This work builds on its predecessor ASTM E2213-03.

802.11p is also used as a basis for the ITS-G5 (ETSI), and geo networking standardization, for vehicle to vehicle and vehicle to infrastructure communication, led by ETSI ITS

ETSI TC ITS (ETSI)

Interoperability and functionality of vehicular communication technologies is an essential requirement according to the Cooperative ITS Mandate (M453) issued by the European Commission and governments in order to enable seamless integration of vehicle to infrastructure communications across Europe.

The mandate is mainly directed to ETSI (the European Telecommunication Standards Institute) and CEN (the European Standards Committee), which have in turn published many standards towards co-operative ITS deployment, in pan European urban, sub-urban and highway environments, in a harmonized fashion, including means of transport such as vehicles, trucks, emergency services and public transport vehicles. Through the joint statement, infrastructure suppliers invite public authorities at national, regional and city levels to collaborate in order to ensure that ITS products and services will ful fill requirements for interoperability and functionality.

ETSI is also one of the main European Standardization Organizations that has been publishing ITS relative specification addressing systems such as, Road Transport Traffic Telematics, Geonetworking and ITS Applications.

Geonetworking is an essential communication service that is required for various collaborative ITS and even electro mobility, applications such as charging spot notification

and others. Geonetworking packet routing makes use of geographical position information for packet transport. It targets the broadcast of packets to a defined geographical region and makes use of multiple ITS access technologies. In order to guide the deployment of the Geonetworking protocol specification on top of multiple ITS access technologies, the specification is separated into media-independent and media-dependent functionalities. Media-independent functionalities apply to all ITS access technologies. In contrast, media-dependent functionalities correspond to define ITS access technologies. Therefore, the Geonetworking protocol specification consists of the standard for media-independent functionality and at least one standard for each media-dependent functionality.

ETSI defines the Geonetworking in ETSI TS 102 636 family of documents (ETSI, 2011) The core of the Geonetworking protocol layer is defined by the ETSI TS 102 636-4-1 standard (ETSI TS 101 556-1, 2012) in the document titled “Geographical Addressing and Forwarding for Point-to-Point and Point-to-Multipoint communications; Sub-part 1: Media-Independent Functionality”.

Communications, Air-interface, Long and Medium range (CALM) (IEEE, 2014)***,*** (ETSI, 2010)

Communications Access for Land Mobiles (CALM) defines wireless protocols and air interfaces for various scenarios, spanning multiple modes of communications and methods in Intelligent Transportation Systems (ITS). These interfaces ensure optimal use of resources available for short, medium and long-range, safety critical communications, using one or multiple means of communication.

CALM defines the following communication modes

- Vehicle-to-Infrastructure (V2I): communication initiated by either roadside or vehicle (e.g. petrol forecourt or toll booth)
- Vehicle-to-Vehicle (V2V): peer to peer ad-hoc networking amongst fast moving objects following the idea of MANETs/VANETs.
- Infrastructure-to-Infrastructure (I2I): point-to-point connection where conventional cabling is undesirable (e.g. using lamp posts or street signs to relay signals)

The CALM abstraction layer decouples the aforementioned communication modes from wireless technologies thus enabling deployment over various links such as:

- Infrared
- GSM (2G, 3G cellular telephone communication technology)
- DSRC 5.8-5.9 GHz (legacy systems)
- Various evolutions of the IEEE 802.11 standard including WAVE (IEEE P1609.3/D23), M5 (ISO 21215), , 802.11p
- WiMAX, IEEE 802.16e
- MM-wave (63 GHz)
- Satellite
- Bluetooth
- RFID

The CALM architecture provides an abstraction layer for vehicle applications, managing communication for multiple concurrent sessions spanning all communications modes, and all methods of transmission.

The European Electronic Toll service (EETS)

Electronic toll collection (E-Tolls) aims to eliminate the delay on toll roads by collecting tolls electronically. ETC determines whether the cars passing are enrolled in the program, alerts enforcers for those that are not, and electronically debits the accounts of registered car owners without requiring them to stop.

EETS seeks to impose a common standard for electronic toll collection throughout the EC. It allows the use of two technologies, 5.8 GHz DSRC tag and beacon systems, and GNSS-based distance charging. The DSRC defined for EETS builds on already defined standards. The European standardization organization European Committee for Standardization (CEN), sometimes in co-operation with the International Organization for Standardization (ISO) developed the following DSRC standards:

- EN 12253:2004 Dedicated Short-Range Communication – Physical layer using microwave at 5.8 GHz (review).

- EN 12795:2002 Dedicated Short-Range Communication (DSRC) – DSRC Data link layer: Medium Access and Logical Link Control (review).
- EN 12834:2002 Dedicated Short-Range Communication – Application layer (review).
- EN 13372:2004 Dedicated Short-Range Communication (DSRC) – DSRC profiles for RTTT applications (review).
- EN ISO 14906:2004 Electronic Fee Collection – Application interface.

Other possible applications of this technology were:

- Emergency warning system for vehicles.
- Cooperative Adaptive Cruise Control.
- Cooperative Forward Collision Warning.
- Intersection collision avoidance.
- Approaching emergency vehicle warning (Blue Waves).
- Vehicle safety inspection.
- Transit or emergency vehicle signal priority.
- Electronic parking payments.
- Commercial vehicle clearance and safety inspections.
- In-vehicle signing.
- Rollover warning.
- Probe data collection.
- Highway-rail intersection warning.

GNSS-based electronic tolling as defined by EETS uses GNSS for measuring the tolling events, DSRC for compliance checking and cellular communications for communicating with charging back offices. The standards used for the communications parts of GNSS-based tolling are the DSRC and cellular data standards already mentioned above.

3.5 I2I, PLC and V2G communications State of Art

This section reviews the wireless and wired communication technologies for infrastructure to infrastructure communications.

3.5.1 *Wireless I2I communication technologies*

Wireless technologies offer affordable network solutions since installation costs for cabling is minimized to base station setup. This principle could possibly apply to smart grid infrastructure networking. Smart metering infrastructure deployment could possibly exploit such wireless networks in order to facilitate Demand Side Management (DSM) services. Several approaches have considered low data rate ICT solutions, but the use of next generation cellular networks will remove limiting bandwidth constraints. Additionally the usage of lower frequency ranges (often frequencies previously occupied by analogue television channels, i.e. digital dividend) for dedicated smart grid services (AMR, DSM, Substation Automation) offers a promising approach for covering rural areas, but the development of future network deployment needs to be taken into account.

Current widely spread cellular infrastructure (GSM, UMTS) can cover applications and services that do not require high data rates and latencies. Enhancements to these cellular network technologies have been reflected in the development of GPRS, EDGE, HSPA. The next generation of cellular networks that is introduced by technologies like WiMAX, LTE and LTE-Advanced, meet the requirements for increasing data rates and decreasing latencies in order to enable real time applications with high throughput demands. Such technologies allow the implementation of producer and consumer architectures as well as substation automation.

Furthermore, several approaches investigate the integration of established radio technologies like satellite technologies (Inmarsat, Iridium, Globalstar, Thuraya, Astra) and TETRA. Due to the near complete coverage achieved by satellite technologies, these approaches are considered in order to offer connectivity in rural areas where ground-based wireless technologies, much less wired, are, mostly out of economic considerations, not an option. Limited data rates, weather dependent reliability and very high latency as well as costly tariffs restrain a comprehensive usage of these technologies for advanced Smart Grid functionality.

3.5.2 Wired I2I communication technologies

Wired technologies (e.g. DSL, FTT, GPON) are currently used to include producer-consumer households and transformer stations in the grid infrastructure. Re-utilization of existing infrastructures is a cost effective solution compared to novel communication infrastructure deployment. Wired ICT, usually provides comparable data rate transmission. The only ICT which is able to fully sustain its entire data rate over large distances is GPON (Gigabit Passive Optical Networks, e.g. Fibre To The Home – FTTH).

GSM's maximum range of 35km, which can be attributed to the timing advance method, is rarely reached in real world scenarios. DOCSIS reaches its long distance through use of a Hybrid Fibre Coax (HFC) topology, where the copper wiring is aggregated onto fibre on a district scale. Compared to wired, wireless ICT shows a much steeper decline of the achievable data rate with increasing range.

The Digital Subscriber Line standard family is one of the prevailing solutions for broadband internet and it provides high data rates and. DSL provides an economic alternative for smart grid communications, given that reliable QoS techniques and security mechanisms deal with non-exclusive use of the medium. On the other hand optical networks guarantee high data rates, low latencies and long ranges. This means that last-mile access in addition to substation automation can be covered by them. Moreover long lifecycles of optical network infrastructure components and technology minimize maintenance costs.

The aforementioned technologies target connectivity in a local level that could cover small scale network clusters.

Coverage of larger areas is covered by WAN (Wide Area Networks). Such networks cover topologies beyond the boundaries of the personal space (Personal Area Network - PAN), buildings / premises (Local Area Network - LAN) and cities (Metropolitan Area Network - MAN). Such networks compose the backbone of the Internet. Technologies at this level mostly use fibre cabling, since it is required to use a medium which can sustain high data rates over these long distances through low attenuation and relatively high resistance against noise. ATM, SONET/SDH, X.25 and Frame Relay are commonly to be found at the backbone of WANs.

Power Line Communication technologies

Use of the power line as a communication medium for data has been a topic of discussion since it has the advantage of re-using infrastructure that can possibly cover large geographical areas. High, medium and low level networks can form an extended network for telecommunications. In October 2004, the U.S. FCC adopted rules to facilitate the deployment of “Access BPL (Broadband over Power Line)”, i.e., use of BPL to deliver broadband service to homes and businesses. Competing organizations such as HomePlug Powerline Alliance, Universal Powerline Association and HD-PLC Alliance have developed specifications. Moreover standardization for supporting high-speed home networking over power lines, phone lines and coaxial cables, led to the approval of the the ITU-T G.hn/G.9960 recommendation. (ITU, 2009).

The IEEE P1901 Draft Standard for Broadband over Power Line Networks defines Medium Access Control and Physical Layer Specifications (IEEE, 2010). Many implementation challenges exist till this moment. The power line network has been designed for electricity distribution, rather than data transfer. The medium has various noise and disturbance characteristics that result in an unreliable channel. The improvement of the transmission rate over the wire is a topic of continuous research. Most of these studies are based on an operating frequency of less than 30 MHz (N. Pavlidou, 2003) (Caffery, 2004). The HomePlug AV system developed by the HomePlug Powerline Alliance has employed adaptive orthogonal frequency-division multiplexing (OFDM) over a bandwidth of 26 MHz, ranging from 2 to 28 MHz, to achieve a physical layer data rate of up to 200 Mb/s (HomePlug Powerline Alliance, 2005). However, it is impossible to meet the requirement for increasing data rates when compared to technologies like, ultra wideband (UWB), which is gaining popularity in modern communication technologies, since it can provide very high data rates using a wide frequency range of 500 MHz. Additionally it offers advantages such as, low-interference to coexisting systems as well as robustness against multipath and simple implementation (Oppermann, 2004).

Broadband PLC technology development takes novel architectural recommendations into consideration such as the introduction of actors like the producer/consumer (e.g. IEEE P1901, HomePlug 1.0/Turbo/AV/AV+, DS2, Panasonic HD, etc.). Moreover capabilities like larger bandwidth, higher modulation schemes and notch filtering, make BPLC technologies, an economic solution for the communication infrastructure on several levels of the Smart

Grid. Furthermore, narrow-band PLC technologies are discussed as last-mile solutions due to moderate installation costs and exclusive usage which provides good QoS.

Narrowband PLC development and standardization activities are very active and multiple solutions have been proposed at both standard and implementation level. One essential concern in standardization is the efficient use of the power line channel in co-existence with other NB PLC technologies. At the implementation level, multiple NB PLC technologies compete in the same product market. (e.g., PRIME, G3-PLC, HomePlug Green PHY, Netricity PLC). In practice, interoperability and co-existence of these solutions in the grid market is still an issue under investigation.

In conclusion, the global presence if the power network make NB PLC a strong candidate for communications within various applications of smart grid. However, the selection of the communication medium and equipment will not follow a single technology, but most likely will be driven by cost effectiveness and the ability to fulfil application specific requirements such as, data rate, reliability, security, emissions, etc.

Table 10 Wired communication technologies

Technology	xDSL	EuroDOCSIS	PLC	GPON	ISDN	Dial-up
Standard	ADSL: ITU-G.991.1 ADSL2+: ITU-G.992.5 VDSL2: ITU-G.993.2	DOCSIS 1: ITU-T Rec. J.112 DOCSIS 2: ITU-T Rec. J.122 DOCSIS 3: ITU-T Rec. J.222	IEEE 1901	ITU-T G.984	ITU-T G.961 ITU-T I.430 T Q.920/921/930/931	ITU-T V-Series
Modulation	Discrete multi-tone modulation	QAM-64/256 (DL) QPSK / QAM-8/16/32/64/128 (UL)	OFDM / Wavelet	QAM-64/256	2B1Q / PCM	PCM
Frequency	ADSL: 25-138kHz/138-276kHz (UL), 138kHz-1,1MHz (DL) ADSL2+: 138-276kHz (UL), 276kHz-2,2MHz (DL) VDSL2: 25kHz-12MHz	50-862MHz (DL) 5-65MHz (UL)		1310nm (UL) 1490nm (DL)	4-80kHz	300-3400Hz

Data rate (up to)	ADSL: 12Mbps (DL). 1,8Mbps (UL) ADSL2+: 24Mbps (DL), 3,3 Mbps (UL) VDSL2: 100 Mbps (DL & UL)	50 Mbps per channel (DL) 27 Mbps per channel (UL) Number of channels dependent on version of standard Typical: 100/5 Mbps Up to: 400/108 Mbps	500 Mbps	1 Gbps (DL & UL)	64k bps per channel, up to 30channels	56 kbps
Coverage	<4km	over 100km (including HFC)	up to 1,5km	over 100km	<8km	<8km
Physical Medium	twisted pair wire	coaxial cable	electrical lines	optical fiber	twisted pair wire	twisted pair copper

I2I charging station communication

Although the charging station is only a part of the infrastructure together with the sensors and actuators, and its communication protocol falls within the generic communication technologies implemented in smart grids, due to the relevance to the project there will be a more detailed look on the communications architecture and protocols used in recent projects. The following refer to static charging stations, however the communication architecture and protocols could possibly be extended for implementation in FABRIC if we consider that one charging spot (of the many) used for dynamic wireless charging corresponds to a conventional static charging station. The main difference is that the charging spot in FABRIC will be energized for a fraction of a second each time (as long as it takes for the vehicle to pass above the spot while travelling) instead of hours of constant operation in the case of a static charger. This may prove challenging for both the electronics and the communication protocols so either different technologies and communication standards will have to be used, or the static charging SotA ones will have to be adapted/extended to support the new operating mode.

Mass market deployment of EVs requires the development of a Vehicle to Grid (V2G) communication system that manages EV charging sessions in order to allow grid load balancing and prevent overloads due to concurrent demand. The standardization of an interoperable V2G communications interface is ongoing in the ISO/IEC 15118 working group

(ISO, 2014). This standard defines the communications interface between the EV and the local recharging controller device. The 15118 standard portfolio consists of the following 5 parts:

- Part 1: General information and use case definition
- Part 2: Network and application protocol requirements
- Part 3: Physical and data link layer requirements
- Part 4: Network and application protocol conformance test
- Part 5: Physical layer and data link layer conformance test

The automotive side of the V2G interface, integrated with the battery management system and HMI interfaces, brings charging services to the vehicle. On the grid side, harmonization with existing grid protocols and services is essential for the successful deployment of an integrated EV to Grid communication stack. The PowerUp project focuses on both, grid and automotive side, integration of the ISO/IEC 15118 communication interface.

In PowerUp an end-to-end EV to Grid communications system has been developed, and validated for both home and fast charging scenarios (AC/DC). Figure 11 depicts the architectural view of the implemented system. According to ISO/IEC 15118 definition, the "Supply Equipment Communications Controller" (SECC) is the infrastructure-side entity for the V2G interface, whereas Smart-Grid systems terminate at the "Smart- Meter" (SM). The definition of SM to SECC integration is an essential aspect in successfully integrating EV's to the smart grid as it is the boundary between ISO/IEC 15118 protocol and existing smart grid metering protocols. In PowerUp ISO/IEC 15118 to COSEM/DLMS protocol translation was proposed in order to perform such an integration.

According to the conceptual reference diagram for Smart Grid information Networks compiled by the National Institute of Standards and Technology (NIST) and the joint CEN-CENELEC-ETSI coordination group, customer facilities (including charging stations and households) will be equipped with Smart Meters. Therefore a possible EV to smart grid integration approach will be to embed a SECC entity into smart meters. SMs currently installed, mostly use narrowband S-FSK PLC technology. However the next generation of SMs is expected to embed OFDM-modulated PLC technologies. Recent development in Dual-mode G3/PRIME chipsets, in addition to capabilities of such superior OFDM links

compared to S-FSK, could pave the way to G3/PRIME deployment in smart metering systems.

The EV to grid communication system developed and tested in PowerUp, consists of two basic communication links:

- *EV to SECC:* This link is based on UDP transport (over UPA/HPGP) with link-local IPv6 multicast addressing to distribute the SECC Discovery Protocol messages. V2G application messages are transmitted over TLS with unicast IPv6 addressing.
- *SM to Control Centre:* Higher layer DLMS/COSEM application messages are transmitted over UDP/IPv6(Over GPRS).

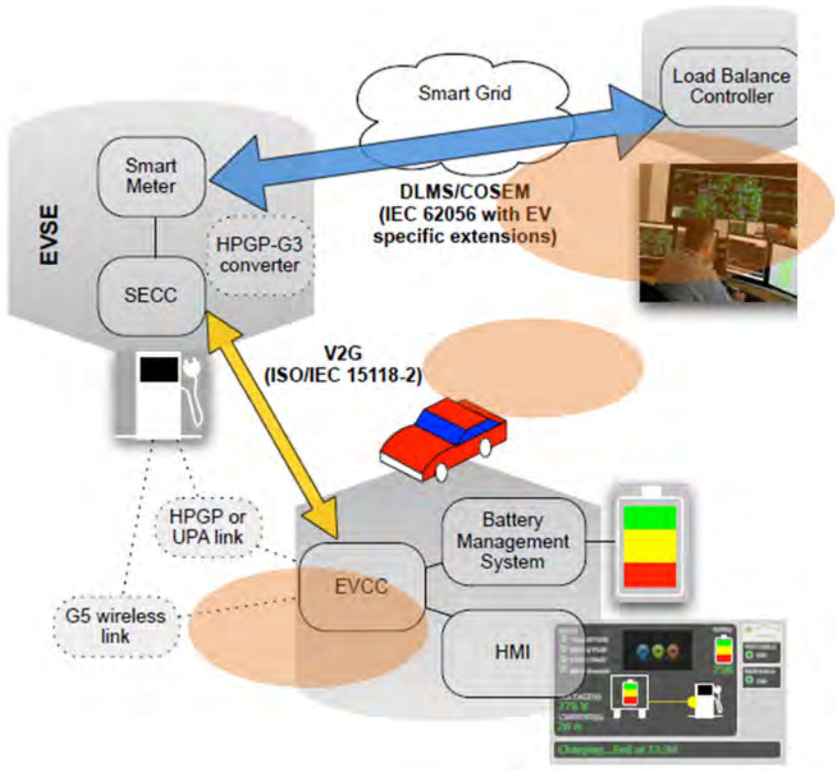

Figure 11: EV to charging station to Grid communication architecture as implemented in PowerUp project

Alternatives to the DLMS/COSEM communication scheme used in PowerUp could include web based messaging and/or the adoption of other grid related protocols as follows.

- Use of the Open Charge Point Protocol (OCPP) for the application layer messaging to the grid control centre. OCPP's presentation layer is based on SOAP XML and

messages are transmitted over the HTTP protocol. Many available tools enable the development of such protocols. However their verbose nature makes them a sub-optimal choice in limited bandwidth environments such as low bandwidth, PLC based, smart grid networks

- Another alternative is the use of the IEC 61850 ‘Distributed Energy Resources’ (DER) protocol for application layer messaging to the grid control centre. IEC 61850 has been designed for electrical substation automation and is being extended to cover communications of distributed resources. An E-mobility extension has been published in IEC Technical Report 61850-90-8. Such an approach enables interaction with the ISO/IEC 15118 interface and thus stands as a viable alternative to the DLMS/COSEM approach selected in PowerUp.

I2I communication with road operators – DATEX II standard

DATEX II (specification for DATa Exchange between traffic and travel information centres) is a European standard for the exchange of traffic information based on a well-known information model using the format Extensible Mark-up Language (XML).

DATEX II can be used for cross-border data exchange between national or regional Traffic Information Centres (TIC) and for exchange between TICs and media or service providers of traffic and travel information.

Allowing the exchange of traffic information to take place directly between control room operating systems considerably increases the safety and performance of transportation networks. With any exchange taking place at the system level, information is transferred instantaneously and does not involve the intervention of the operator, allowing for faster more responsive management of road networks.

This ‘dynamic system state’ lies at the heart of the concept of Intelligent Transport Systems (ITS). When considering the volume, availability and accuracy of data, combined with the many descriptors of traffic state or situations, the importance of the concept becomes obvious.

The harmonisation and standardisation of data structures and data exchange services are fundamental challenges for both the information society as a tool to meet the ITS interface challenge.

DATEX II is of relevance for all applications where dynamic information on the transport systems and notably the road system is concerned.

The common usage areas are:

- Rerouting, network management and traffic management planning. Motorway networks and urban networks are regarded as closely connected here.
- Lane or line control systems and related applications like ramp metering, dynamic speed limits and overtaking control.
- Linking traffic management and traffic information systems.
- Applications where information exchange between individual vehicles and traffic management is crucial, like for Car-to-infrastructure systems.
- Applications where information exchange between management systems for different modes is crucial, like multi-modal information systems.
- Applications where the exchange of measured data is important.
- Provision of services in the framework of road management with a strong link to network safety or performance like Truck Parking.

3.6 FABRIC anticipated communication interfaces and SotA

This section reviews on possible communication between two parties the range between these two parties and feasible communication technologies.

3.6.1 Long range Electric Vehicle on the Road to Control Centre (Long range V2X)

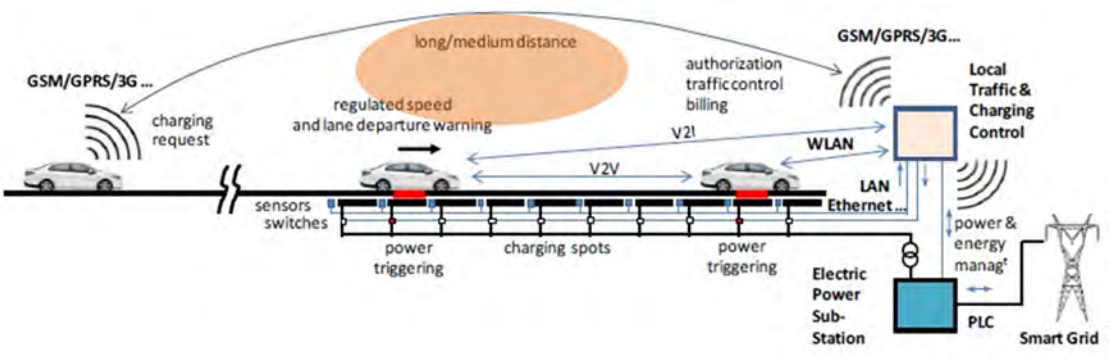

Figure 12: FABRIC long/medium range V2I communication

Feasible communication technologies

UMTS, HSDPA, LTE, ITSG5 are the communications technologies which are considered feasible within FABRIC.

State of the Art

The feasible communication technologies for mobile communication on the road are already available in general. Inside the electric vehicles cellular communication is currently available and for the future it is planned to extend the functionality with LTE and ITSG5.

3.6.2 User with Web Access to the Control Centre

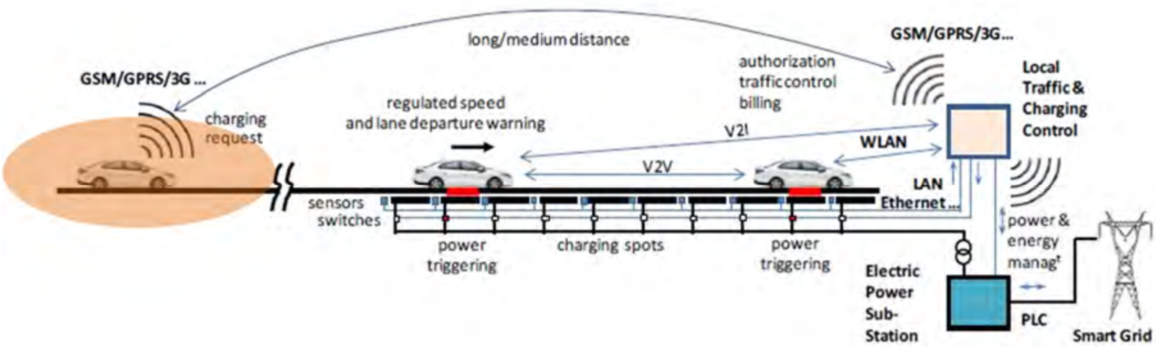

Figure 13: FABRIC Driver to infrastructure communication

1.6.2.1 Feasible Communication Technologies

Stationary: DSL (when accessing from desktop computer, prior to the trip)

Mobile: UMTS, HSDPA, LTE

1.6.2.2 State of the Art

Stationary and mobile communication by web access is used today for many different applications e.g. online banking, access to online stores and many more. For the application addressed in FABRIC, mainly mobile communication solutions are relevant since the user is supposed to access the control centre remotely from the OBU. All kinds of mobile communication technology can fulfil the communication requirements for the interface between EV user and Control Centre (e.g. GPRS, UMTS, HSDPA, LTE).

3.6.3 Vehicle to Road Side Unit short range communication (Short range V2I)

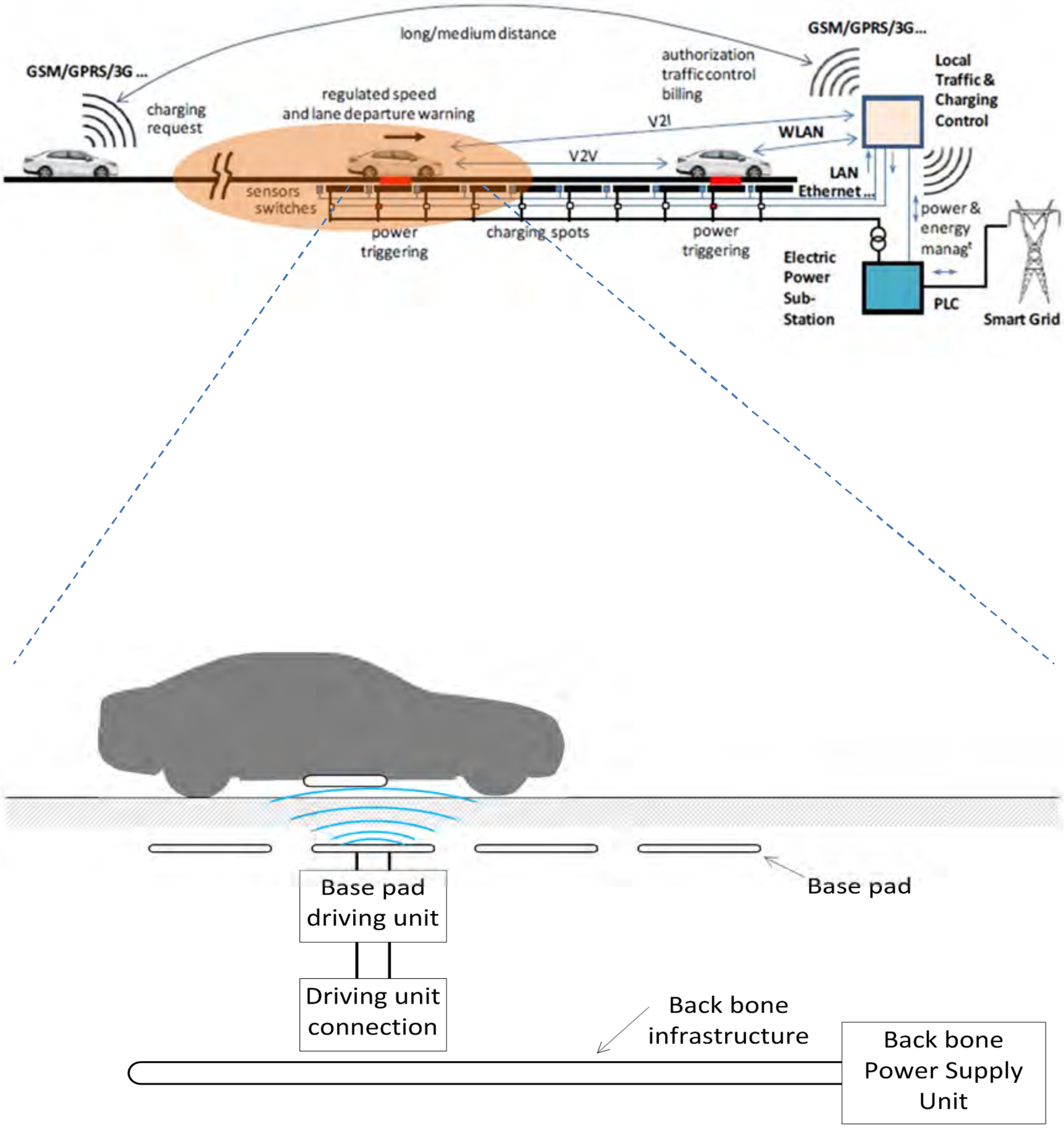

Figure 14: FABRIC short-range V2I communication

Feasible Communication Technologies

Bi-directional communication between the vehicle and RSU sensors/actuators is required. Very low latency is a major requirement since the alignment of the vehicle with each of the charging pads will last only for a few ms due to the vehicle's high velocity.

- ITSG5 based on IEEE 802.11p
- DSRC
- LTE

State of the Art

Current ITS projects focusing on EV support use ITSG5 and DSRC technologies for short range communications between the vehicle and the charging infrastructure due to low latency.

3.6.4 Vehicle to Infrastructure medium range communication (Medium range V2I)

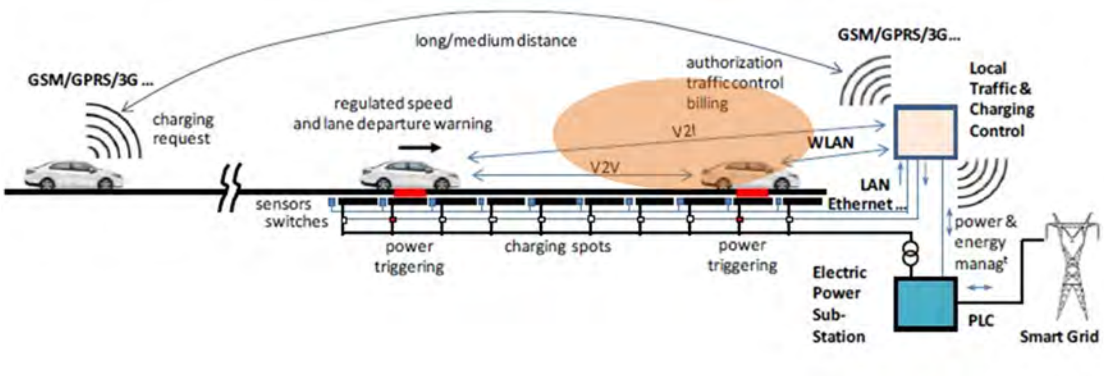

Figure 15: FABRIC medium-range V2X communication

Feasible Communication Technologies

UMTS, HSDPA, LTE, ITS-G5, CAL are all feasible technologies which could address the FABRIC medium range V2I requirements.

State of the Art

See 3.4.1 for a description of the current state of the art.

3.6.5 Vehicle to Vehicle short range communication (Short range V2V)

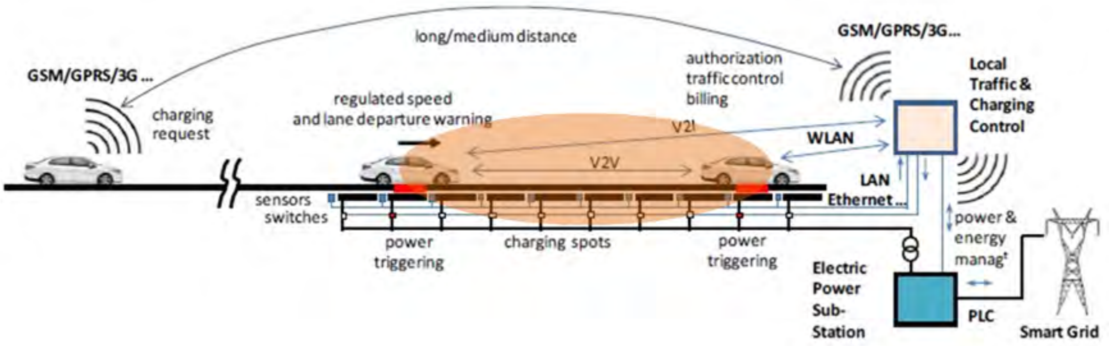

Figure 16: FABRIC V2V communication

1.6.5.1 Feasible Communication Technologies

Low latency communication is required. Typical ITS communication restrictions and requirements apply.

- CALM
- DSRC
- ITS-G5

State of the Art

See section 3.4.1

3.6.6 Infrastructure to Infrastructure communications (I2I)

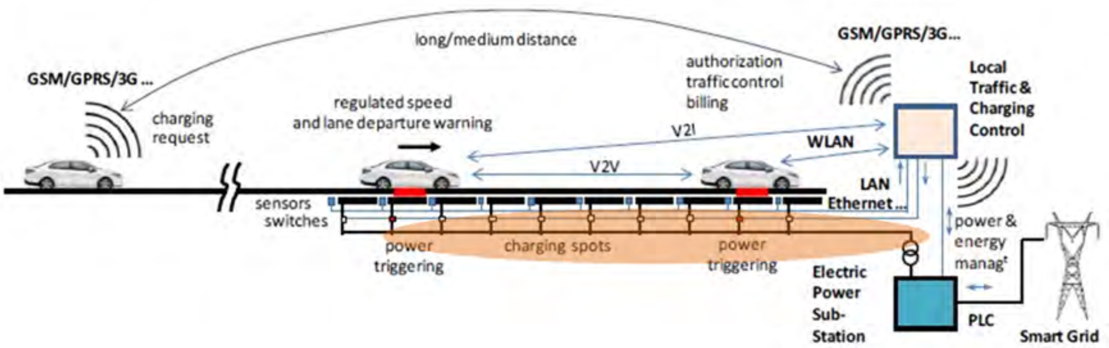

Figure 17: FABRIC I2I short/medium-range communication

Feasible Communication Technologies

Bi-directional communication between the sensors and actuators and a control centre is required. Very low latency is a major requirement since the power supply ramp-up time must be a few ms.

- Secure internet connection: DSL, Ethernet, WAN
- PLC
- LTE advanced/CALM
- DLMS/COSEM (IEC 62056)
- IEC 61850 standard for subnet automation

State of the Art

In the environment of substation automation, the IEC 61850 standard already is well known adopted. This standard also enables functionalities of smart grids and can be extended to support the embedding of charging spots into the power grid. The IEC 61850 offers a common protocol for all the different devices in the smart grid and ensures interoperability.

3.6.7 Energy Supplier, road and other operators to Control Centre

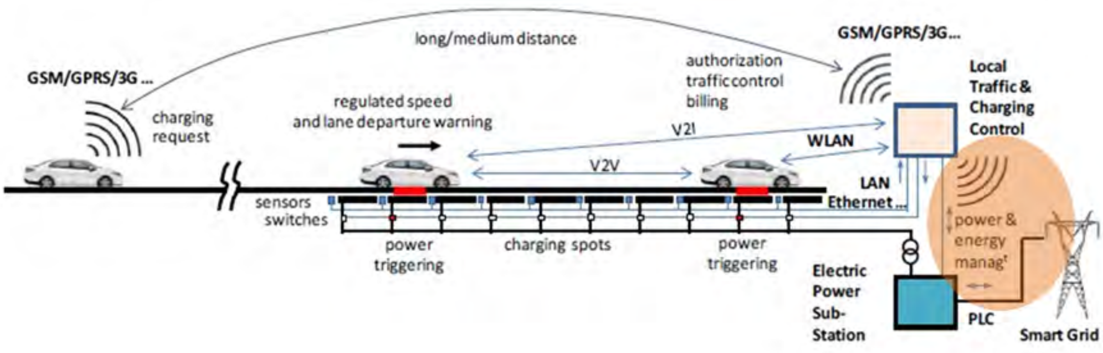

Figure 18: FABRIC I2I long-range communication

Feasible Communication Technologies

The interface must provide the secure transfer of tariff and other grid related information from the DSO to the Control Centre. In addition traffic, weather and other information from external control centres must be able to reach FABRIC in a timely and secure manner.

- Internet connection: DSL, Ethernet, WAN
- GSM/GPRS/LTE

State of the Art

All technologies mentioned are in use.

3.6.8 Summary

Communication	Feasible communication technology
Long range Electric Vehicle on the Road to Control Centre (Long range V2X)	UMTS, HSDPA, LTE, ITSG5
User with Web Access to the Control Centre	Stationary: DSL (when accessing from desktop computer, prior to the trip) Mobile: UMTS, HSDPA, LTE
Vehicle to Road Side Unit short range communication (Short range V2I)	ITSG5 based on IEEE 802.11p DSRC LTE
Vehicle to Infrastructure medium range communication (Medium range V2I	UMTS, HSDPA, LTE, ITS-G5, CAL
Vehicle to Vehicle short range communication (Short range V2V)	CALM DSRC ITS-G5
Infrastructure to Infrastructure communications (I2I)	Secure internet connection: DSL, Ethernet, WAN PLC LTE advanced/CALM DLMS/COSEM (IEC 62056)

	IEC 61850 standard for subnet automation
Energy Supplier, road and other operators to Control Centre	Internet connection: DSL, Ethernet, WAN GSM/GPRS/LTE

3.7 Summary and conclusions

In this section a review of existing communications is summarized. These communication technologies and standards may be used as is, or adapted to facilitate the communication needs within FABRIC, regarding communication of the Vehicle with the infrastructure both short-range (with sensors, actuators and RSU) and medium-range (with a control centre, which could relate to grid or traffic management or real-time charging management). This is only a preliminary view of the system and its communication interfaces in order to identify the available, relevant communication technologies. The final system architecture, as well as its communications will be defined in detail in WP22 and WP24 that focus on the definition of the system's concept, ICT architecture, functionalities, boundaries and communication interfaces.

4 STATE OF ART POWER TRANSFER

This section presents a review of power transfer solutions. The report aims to pull together information that can be used to compare the state of art against the user needs and requirements in order to develop a conclusive gap analysis. It should be noted that this review was a desktop study with the input from the relevant solutions provider; therefore the facts and figures are correct at the time of writing.

Power transfer solution can be categorised in two ways, namely by type of connection, and by operating environment.

Two types of connection are considered, namely wireless and conductive. Wireless solutions transfer power across an air gap, typically making use of magnetic induction. Magnetic induction transfers power from a primary coil to a secondary coil placed in close proximity, as described in 2.1.1. Other solutions are possible as described in 2.1.2, but are not in common use.

Conductive power transfer uses a physical connection to transfer power. This is commonly used on rail systems, but is less common on roads where the only common usage is in trolley buses. Conductive systems are described in more detail in 2.1.3.

For the purposes of this review, we consider three types of operating environment, namely static, stationary and dynamic environments.

In the static operating environment, power is transferred to a vehicle which is stationary, and expected to remain so for a significant time. This type of system is typified by a parked vehicle. In these systems it is acceptable to require the driver to make a conscious decision to commence charging.

In the stationary operating environment, power is transferred to a vehicle which is stationary for a short time, for example at a bus stop or taxi rank, or even when queuing at a junction. In these systems it is expected that charging will happen automatically with driver intervention. As connection times are short, power transfer rates need to be higher than for static charging. Note that the terms static and stationary are not universal, and indeed in some publications the definitions are exchanged.

In the dynamic operating environment, power is transferred while vehicle are moving in normal traffic. These are the most complex operating environments where connections must be made and broken in fractions of a second.

In the following sections we consider the current state of the art in power transfer technologies in the following sections:

- Section 4.1: dynamic power transfer solutions being researched in FABRIC, including both wireless and conductive systems.
- Section 4.2, power transfer solutions being developed in the UNPLUGGED project
- Section 4.3, other wireless dynamic power transfer solutions
- Section 4.4, other wireless static and stationary power transfer solutions
- Section 4.5, other conductive power transfer solutions
- Section 4.6, a summary of research projects on power transfer

4.1 FABRIC Dynamic Solutions

This section describes the state of art of power transfer solutions from the FABRIC partners. These systems will be developed and tested for FABRIC project. We consider four wireless solutions (from Polito, Saet, Scania and Vedecom) and one conductive system (from Volvo)

4.1.1 Polito CWD WPT (wireless)

Politecnico di Torino developed their Charge While Driving (CWD) solution in cooperation with Centro Ricerche Fiat (CRF). The solution is based on dynamic wireless resonant inductive coupling principle. This system is currently in development and POLITO aims to perform first tests in the Italian test site early as June 2014.

The primary segment is 9 metres in length enclosed in a single plastic mould, each segment contains five 1.5 metre coils. However number of coils per segment can be varied depending on the development of the system. The operational temperature within the primary is maintained by natural air cooling. The primary coils collect the power from the low voltage three phase connection point, and the road side control system converts the AC voltage to DC and then to a 600V 100kHz waveform in order to transfer the power through the air gap to the secondary coil. As this system is still under development, specifications are preliminary and subject to change.

Specification

Parameter	Value
TRL Level	4
Operational speed	50 km/h
Foreign object detection	none
Voltage	600 VDC(output)
Current	34 A

Power rating and Power Range	20kW
Power Factor	Near 1
Quality Factor	5-15
Overall System Efficiency	>75%
Operating Frequency	20-200kHz
Air gap	20cm
Distance between supply feeds	Supply from the Low voltage distribution for each segment.
Communication protocol (ISO 12118, IEC 61851 etc)	CAN on Wi-Fi
Communication Method (wireless, Bluetooth, etc)	WLAN
Ground Module Dimensions	Segment: 0.5x9x0.024 (W x L x H) Coil: 0.5x1.5x0.02m
Road side Equipment Dimensions	1.2x0.6x0.5m
On-vehicle equipment Dimensions	0.7x0.3m
Coil/ loop life time	25 years
Coil / cable material	Copper litz
Structural integrity (max load)	unchanged
Friction/skid resistance	unchanged

Installation and Maintenance

The coils are embedded 2 cm below the road surface, enclosed in plastic casing and the control systems are located by the road side. The road surface remains unchanged where maximum load capability and skid resistance should remain as standard pavement requirements The POLITO solution require 1m metallic clearance under the road surface in order to minimise the effects of magnetic waves on other underground infrastructure such as telecom cables. The secondary coil is fixed to the bottom of the vehicle, centred with respect to the wheels.

Communications

One of the important technical challenges of the eCo-FEV project was to build a prototype for "Charging While Driving" (CWD). eCo-FEV project is another European project concentrating on creating an integrated electro mobility IT platform (Eco-fev). CWD technology enables the transmission of energy from charging infrastructure to FEVs in mobility. Besides the challenges induced by the need of power electronics for the energy transmission and the requirements of electromagnetic compatibility (EMC), CWD also poses many ICT-related challenges. First one is the need for a wireless communication between the EV and the EVSE. This communication is not only needed by the charging process itself, it is also required to manage the charging processes. For the charging process, the EVSE and EV need to exchange information

regarding the charging parameters including the length of the coil-group, speed range, antenna rated power and so on. During charging, the EVSE might give the EV additional information regarding the position of the FEV or the position adjustment information. The requirements in eCo-FEV are on the basis of designing the wireless communication between EVSE and EV. Although the ISO standard ISO 15118 aims at addressing the EVSE-EV communication for the conductive charging cases, its extension in the parts 6 (General Information and use case definition for wireless Vehicle to Grid V2G communication), part 7 (Network and application protocol requirements for wireless communication), and part 8 (Physical layer and data link layer requirements for V2G wireless communication) to cover the wireless charging are still in draft-phase. Thus the experiences and results gained in the eCo-FEV project would make a promising contribution towards shaping the future of CWD-Technology.

Regarding the vehicle to road side unit short range communications and V2V communications ITSG5 based on IEEE 802.11p (5.9GHz) is considered since it seems to be the most promising technology for low latency wireless communication. An implementation example can be found here:

http://www.greencarcongress.com/2013/10/20131017-brusa.html

On the other hand, legacy communication networks such as cellular network and Internet are used for communication between FEVs to backend and between infrastructure systems.

4.1.2 Saet Spa- Induction powered vehicle (IPV) (wireless)

IPV has been developed by Saet group, and power transfer principle is based on wireless resonant inductive power transfer. The system is currently in development and it will be tested in the Italian site for the FABRIC project demonstrations. Saet Spa aims to test the system on a single lane with non-electrified intervals in between power transfer modules. The vehicle speed is restricted to 80km/h in order to achieve maximum efficiency and each segment is 25m long, therefore the vehicle has a chance to collect power for 1.125 seconds per segment, the power transfer is rated 100kw, where one vehicle at the time can collect power on a segment. As this system is still under development, specifications are preliminary and subject to change.

Specification

Parameter	Value
TRL Level	4
Operational speed	80km/h
Voltage	Input: 400AC 3phase LV

Power rating and Power Range	Up to 100kW, likely to operate at 30 – 50 kW in FABRIC for interoperability
Power Factor	0.9
Quality Factor	6
Overall System Efficiency	70-80%
Operating Frequency	Normally 85 kHz, but can operate at 60-150kHz for interoperability
Air gap	25cm
Effective misalignment tolerance (x,y,z)	X= Y=50cm z=1-2cm
Ground Module Dimensions	Coil: 2 x 1 m (subject to revision)
Distance between supply feeds	Each segment is connected to the LV supply feed
On-vehicle equipment Dimensions	Secondary coil: normally 50 x 50 cm, but can operate different sized secondary for compatibility
Coil/ loop life time	10-15 years (20 years entire system life time)
Coil / cable material	Litz, Aluminium
Operational temperature	55 C

Installation and Maintenance

The primary coils are embedded 5cm below the road surface and the power control equipment is located in containers by the road side, as shown in Figure 19. The primary coils are closely spaced and cover the width of a vehicle to cope with misalignment. The road structure and skid resistance values remain unchanged but the system operates at its optimum level on non-metallic road surface material.

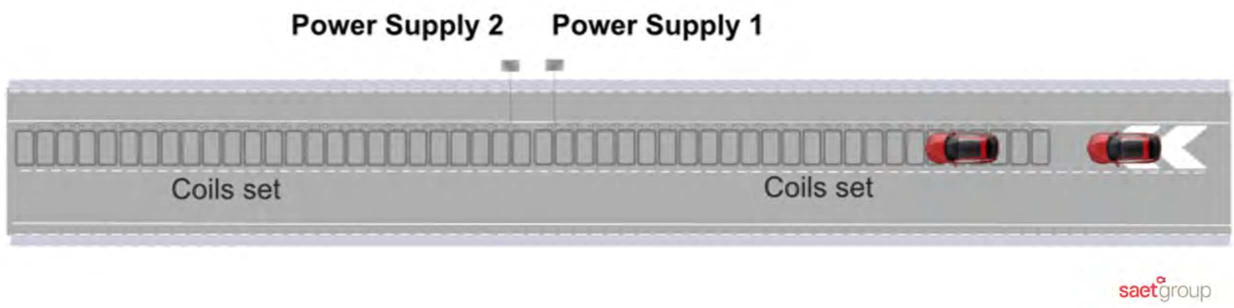

Figure 19: Saet layout concept

4.1.3 *Scania Bombardier Primove (wireless)*

Scania is in collaboration with Bombardier to develop Primove for road vehicles. Primove has been developed to transfer power wirelessly from the grid to the trains. The solution is based on wireless magnetic resonant theory where primary infrastructure consists of road embedded loops and the power is collected by pick up coils under the vehicle.

Previously Bombardier had tested their inductive power transfer system statically and dynamically on a bus and an electric car in Flanders drive project called “Continuous Electric Drive” and for “Slide-in Electric Road Systems”. This technology can provide 80 KW to a bus dynamically and 22KW to a car in static mode and Scania had tested Primove highways system on a test track, the total length of the track was 300m, and it contained four, 20 m electrified segments.

Figure 20 shows the Bombardier’s Primove dynamic power transfer system, The road side power supply is directly connected to the medium voltage level (10KV). The substation collects the 10KV AC from the grid and the transformers step down the voltage level to 400VAC, this process is followed by rectification of 400VAC to 750VDC. 750VDC power is transferred from road side to the underground infrastructure. The underground equipment consists of an inverter, to convert DC voltage to high frequency (20 kHz) wave, segments of loop/coils to transfer the power, and the vehicle detection loops to recognise the vehicles and control electronics to electrify correct segment

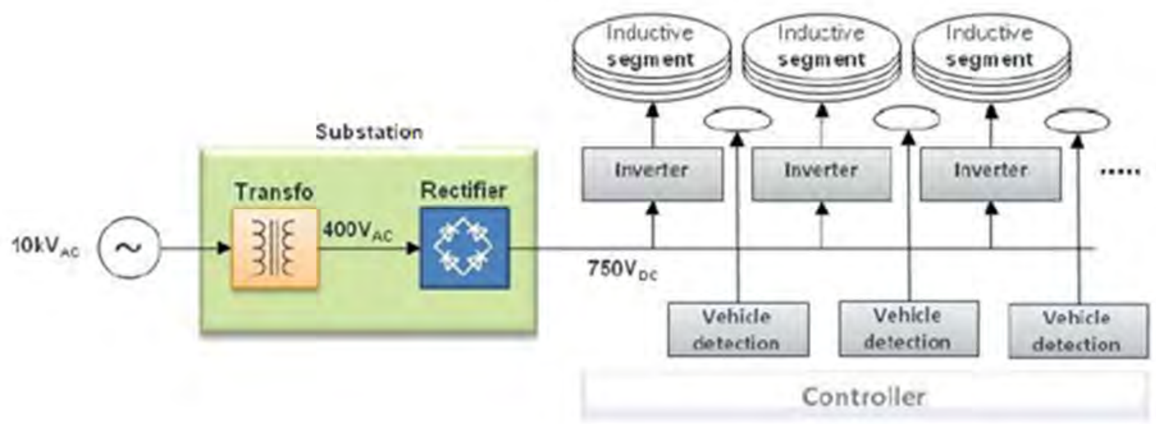

Figure 20: Bombardier dynamic power transfer system

On-board components consist of;

- Pickup coil to collect the power from the primary coil/loop
- Rectifier to convert 20 kHz, three phase AC power from the pickup coil to the DC power

- Moveable arm platform to raise the pickup into a locked position when the vehicle is not using the Primove highway.
- The pickup has a linear 3-phase winding with taps to allow for wide gap and alignment variations.
- Vehicle detection loop transmitter
- Battery
- Resistor

The Primove highway system is safe by design, standard good practice ensure that the Primove system is safe mechanically and electrically. The high values of magnetic flux employed across a short air gap can be an issue to surroundings. Due to exposure to electromagnetic waves, however a novel Primove transformer restricts the high magnetic field to a very close proximity of the pickup under the vehicle. The exposure to high fields around the vehicle is controlled, as the segments are only active when the vehicle is located on top. Any person immediately next to the highway would experience only very small fields much below standard exposure limits.

Specification

Parameter	Value
Costs	£ 2.55m/km (£1.3m projected)
Voltage	Input: 10kV Output: 750 VDC
Current	Up to 400A per Phase
Power rating and Power Range	Up to 200kW
Overall System Efficiency	80% - 90%
Operating Frequency	20Khz
Communication Method (wireless, Bluetooth, etc)	Antenna loop between the road and the vehicle
EMC, EMF	Meets the standards
EM Exposure	Under normal operation the magnetic field will be less than 6.25 uT in all public areas and in the drivers cab. This will be assured by design and operational controls and demonstrated by testing. This field level is lower than the recommended level for public exposure (ICNIRP, 2010) and is safe for all modern

	pacemakers (VIDE, 2002).
Harmonics (THD % V & I)	The Primove system has been shown to meet EN standards for electromagnetic compatibility except at the primary power transfer frequency, where it has been demonstrated and accepted that no harm arises from the exception. The TÜV SÜD has confirmed that the Primove system complies with the regulations and requirements regarding electromagnetic field emissions (EMF) and compatibility (EMC).
Ground Module Dimensions	20m length
On-vehicle equipment Dimensions	2m x 1m
On-vehicle equipment weight	Pickup + moveable platform is 330kg Primove control and rectifier is 60kg
Distance between feeder points	40 m
Maximum operation temperature	-40-40 ^{0}C
Friction/skid resistance	Same as existing pavement

Installation and Maintenance

The primary loops are embedded 40 mm under the pavement surface, in a special form that holds the shape of the windings while the asphalt is applied. All Primove primary coils, antennas, star point junctions, and connector leads are installed prior to the final road resurfacing. In the areas where utilities run under the road a layer of aluminium is required between the Primove ground module and the utilities. The Primove ground module excavation is 200 mm deep and 800 mm wide. The Primove coils are prefabricated to preserve coil and core shape. The carrier is fixed to the roadbed and the cable ends routed to the WPC. Finally the road is resurfaced to complete the segment's installation.

The design target is 5000 hours between service affecting failures. The Primove wayside system excluding traction substations is expected to have availability greater than 99%.

4.1.4 Vedecom Qualcomm HALO (wireless)

The Vedecom solution is provided by Qualcomm, who propose to supply their HALO wireless charging solution. The available details are given below.

- Charging solution name
  - *Qualcomm Halo™*
- System manufacturer / IP owner
  - *Qualcomm*
- High level system description (how does it work, possible schematic/diagram)
  - *Wireless Electric Vehicle Charging (WEVC) is a simple, no fuss solution for charging Electric Vehicles (EV). Qualcomm Halo™ WEVC technology uses resonant magnetic induction to transfer energy between a ground-based pad and a charging pad on the electric vehicle. The Base pad and the Vehicle pad are magnetically coupled and tuned, and energy is transferred efficiently between the pads. Power is converted to Direct Current (DC) by the on board controller and used to charge the vehicle's batteries.*

Figure 21: Qualcomm HALO system

- System type (wireless or conductive)
  - *Wireless*
- On-road Charging capability (demonstrated capability, potential to develop dynamic system)
  - *Dynamic extension of demonstrated static charging technology*

- Description of Key Components / modules

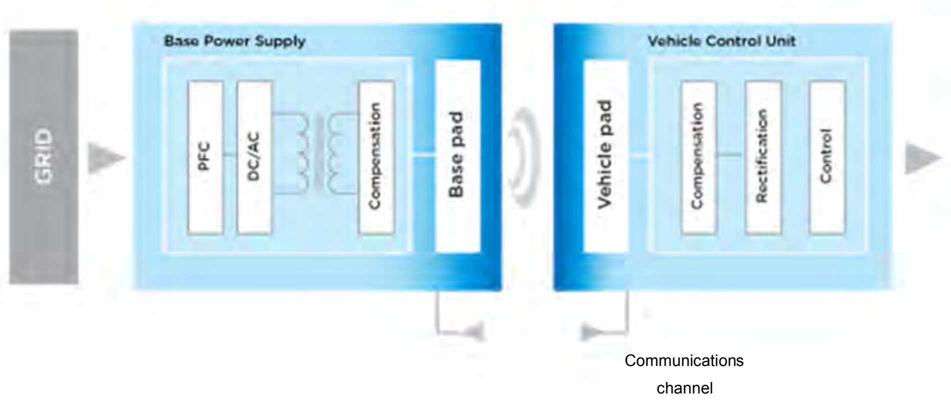

Figure 22: HALO key components

- Application in other industries
  - *Technology has been applied to material handling robots in automated factories.*
- Existing installations / trials / demos
  - *Trial of static charging technology being performed in London*
- Actual or proposed deployment method (continuous, interval, all lanes, single lanes, speed restrictions, etc…)
  - *Dependent upon application*
- Effect on driving performance (e.g. vehicles oscillate as they enter/leave charge point)
  - *No known effect on driving performance*
- Foreign object detection (recognition of object between source and receiver)
  - *FOD system developed for static application. Required specification for dynamic application to be assessed.*
- Foreign object removal method
  - *Manual intervention*

Specification

Parameter	**Value**
TRL Level	4
Foreign object detection	Requirement for FOD not available
Voltage	300-400V DC on vehicle request
Current	Up to 67A on vehicle request
Power rating and Power Range	Up to 20kW on vehicle request
Overall System Efficiency	Target 80%
Operating Frequency	85kHz

Airgap	Variable – as required by vehicle and system installation requirements (surface, flush or buried) Coil to coil distance of 125 – 175mm supported.
Effective misalignment tolerance (x,y,z)	Target Y tolerance of +/- 200mm
Distance between supply feeds	50m
Distance between feeder points	50m

- Information exchange between charging solution and vehicle (charge level, vehicle suitability, etc.)
    - *Yes (CAN bus)*
- Safety & Protection
    - *As appropriate*
- Maximum allowable speed of the vehicle during charging
    - *Not available >60kph*
- Maximum power supply (number of vehicle a segment can provide power)
    - *1 vehicle at 20kW per 25m segment*
- Coil dimensions and number of coils per segment (specific to wireless)
    - *Proprietary information*
- Integration with vehicle (e.g. location on the vehicle)
    - *Underfloor receivers*

Installation and Maintenance

- Installation method (e.g. on/under the surface, roadside (PE) equipment)
    - *Flush-mounted with roadside power supply for FABRIC for ease of maintenance. Expectation of buried on public roads.*
- Road surface requirement (A specific material the system works well or doesn't work well with)
    - *Not available – steel reinforcement in concrete to be avoided in vicinity of system*
- Distance between road surface and source coil (including depth under the road if embedded)
    - *Variable*
- Structural integrity (maximum load capability)
    - *As specified for application*

4.1.5 VOLVO- Slide-in Electric Road System (ERS) (in-road conductive system)

Volvo's ERS system is based on conductive energy transfer, the power is transferred from the rails that are in flush with the road, to the vehicle via on-board pantograph. The ground module

consists of positive rail and ground rail in parallel, the system also has an additional ground rail next to the positive rail to prevent creep current over long distances. Figure 23 shows the ground module set up for ERS system. 750 VDC substations are located every 968m to collect power 30 KV, then step this down to 800 VAC, the 800 VAC runs along the roadside and connected to the road side equipment every 88m. There are manholes with two power boxes powering two 44 metre, the power boxes convert 800V AC to 750DC segments. Each section consists of 22 sets of 44m rails and each segment provides energy to one ERS vehicle at one time. 210 mm^2 copper cables are required for 750 VDC and additionally 210 mm^2 copper cables with 0 VDC for return current.

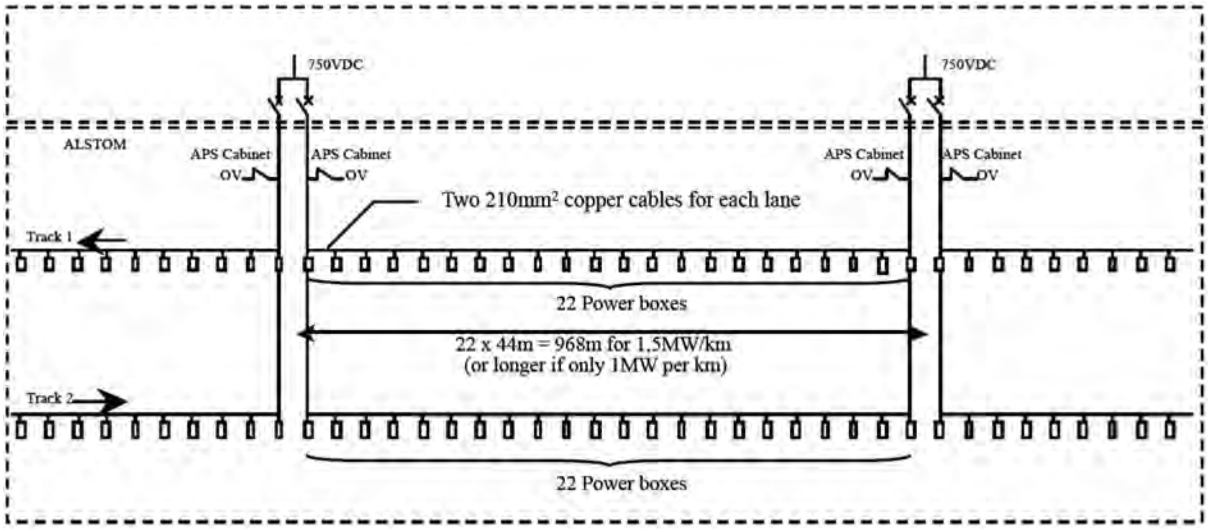

Figure 23: Ground module set up

The solution was developed in partnership with Alstom and the system was demonstrated in Volvo's test site in Sweden. Alstom has developed the ground systems such as conductive rails, control and protection electronics and connections to the grid. Volvo has developed on- board solutions with support from Swedish Universities and Institutions.

Alstom has developed the road embedded rail conductive system called Aesthetic Power Supply (APS) in 2003. This solution was developed as an alternative to the overhead line electrification, to reduce visual pollution caused by masts and overhead lines in crowded urban areas. The tram version of APS system is implemented in Bordeaux, Reims, Angers and Orléans. The trams on APS track have covered more than 12.5 million km. There are more projects under construction in Tours, Bordeaux and Dubai. Once these projects are complete the APS will equip 188 tramways and 63 km of single track.

The Aesthetic Power Supply presents no danger to persons or equipment. The solution develops voltage only in the section that is physically enclosed within the area occupied by the vehicle. This system is designed to supply 1.1MW to the tramway at 750VDC and 1500A. The system is compatible with all existing tram lines including crossings and turnouts. As shown in Figure 24 the power boxes (PB) which supply energy to the APS tracks are fed from 900kW substations installed every 2 km and each rail segment is 11m, where conductive section is 8m and isolation interval is 3m.

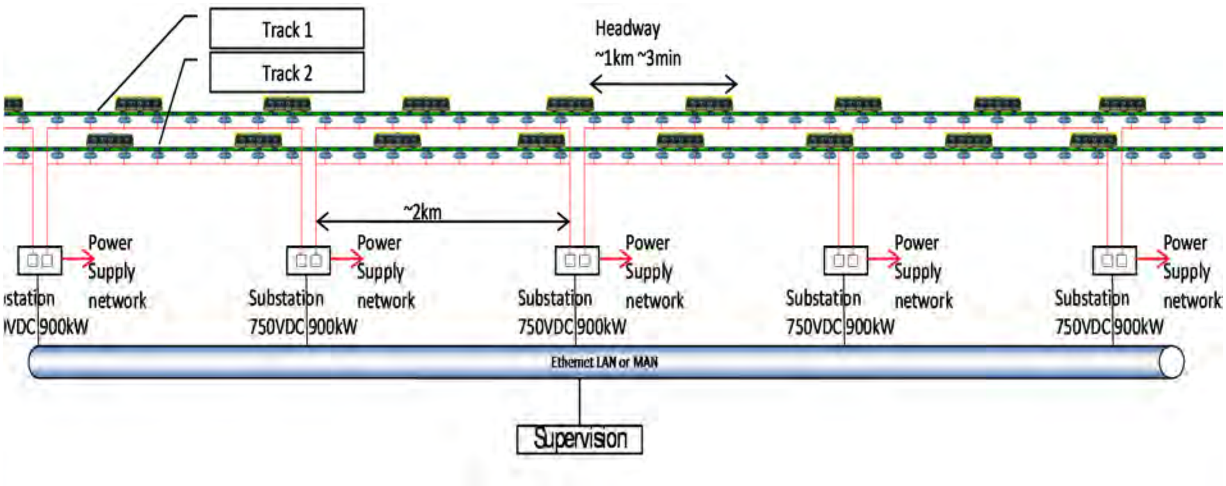

Figure 24: APS Principle

The on-board equipment consists of two collector shoes, switching and control unit and a battery to provide traction in non-electrified intervals. The trams are equipped with two collectors shoes sliding on the same segment, the collector shoes are spaced at least 3 metres apart to ensure at least one collector shoe is collecting power at any time, when the vehicle is on power transfer rails.

Figure 25 shows two 200KW pick-up pantograph prototypes designed by Volvo. The first pickup is the “turning pickup”, where the pickup’s lateral movement is controlled by a rotating electric motor, which is attached to the vehicle body. A linear electrical motor is used for the vertical movement of the pantograph; this motor is the part of the pantograph moving body.

The second pantograph is the “linear pickup”, where the the lateral movement is controlled by a linear movement, along a straight axis between the 2 main frames of the vehicle body. A Pneumatic actuator is used to move the pickup vertically; the high pressure compressed air for the pneumatic system is supplied from the vehicle pneumatic system.

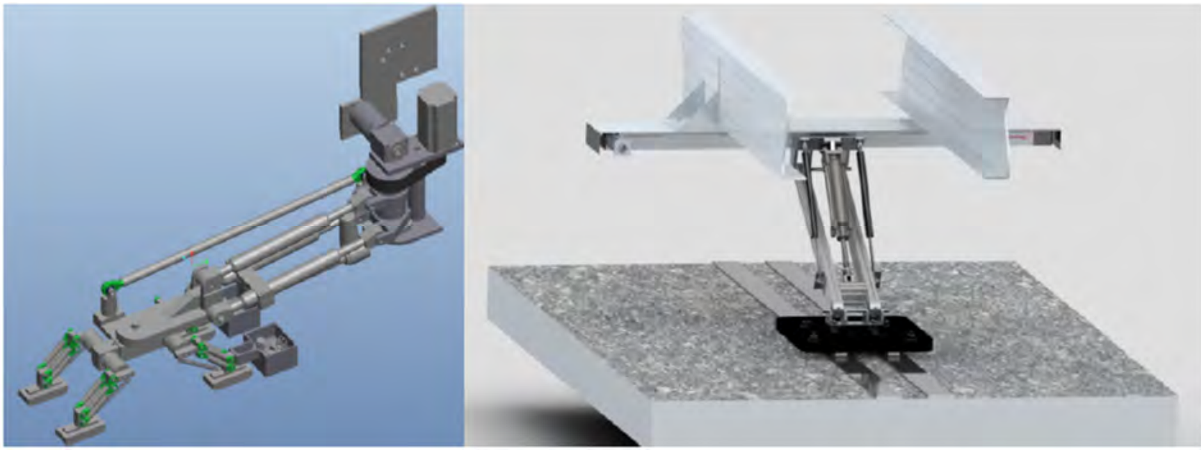

Figure 25: Energy Collection Pantographs

The test results show that the pickups can maintain physical contact between the vehicle collector shoes and the ERS conductive rails up to 50 cm lateral offset, when vehicle is operated in normal manner up to speeds of 70km/h.

Specification

Parameter	Value
TRL Level	3-4
Costs	£786000/km, this does not include installation and commissioning costs.
Foreign object detection	No
Voltage	690V (750V from substation)
Current	175A
Power rating and Power Range	120kW
Power Factor	Not measured (expected to meet minimum grid requirements)
Quality Factor	N/A
Overall System Efficiency	97%
Operating Frequency	N/A
Effective misalignment tolerance (x,y,z)	0.5metre
Communication protocol (ISO 12118, IEC 61851 etc)	Not yet approved
Communication Method (wireless, Bluetooth, etc)	Vehicle to Power Box: Wireless RF; Power Box to APS cabinet: CAN; APS cabinet to management system: Ethernet MAN or RDS
EMC, EMF	Expected to be within the limits of specified standards. Could possibly be a problem with arcs.
EM Exposure	expected to be within the limits of

	specified standards
Harmonics (THD % V & I)	Not measured (expected to meet IEC 61000-3-4
On-vehicle equipment Dimensions	0.5x1,5x0,5m
On-vehicle equipment weight	Estimated for first prototype: • Pickup (+80kg) • Power converter (+40kg)
Distance between feeder points	Grid connection every 968m, Power boxes (switches) in manhole every 88m
Maximum operation temperature	85 ^{0}C

The speed of the vehicle is the key factor on determining the length of the live segments, for safety reasons the power from the ground module to the vehicle will only be activated between speeds of 60km/h to 100 km/h. therefore the systems uses speed detection loops to activate the power supply. Figure 26 shows the speed detection loops that monitor vehicle speed and the direction. The signal from the loops detect the direction of the vehicle with long pulse first, then two short pulses indicating vehicle is moving from left to right, and speed is calculate by the time it has taken to drive over the detection loops.

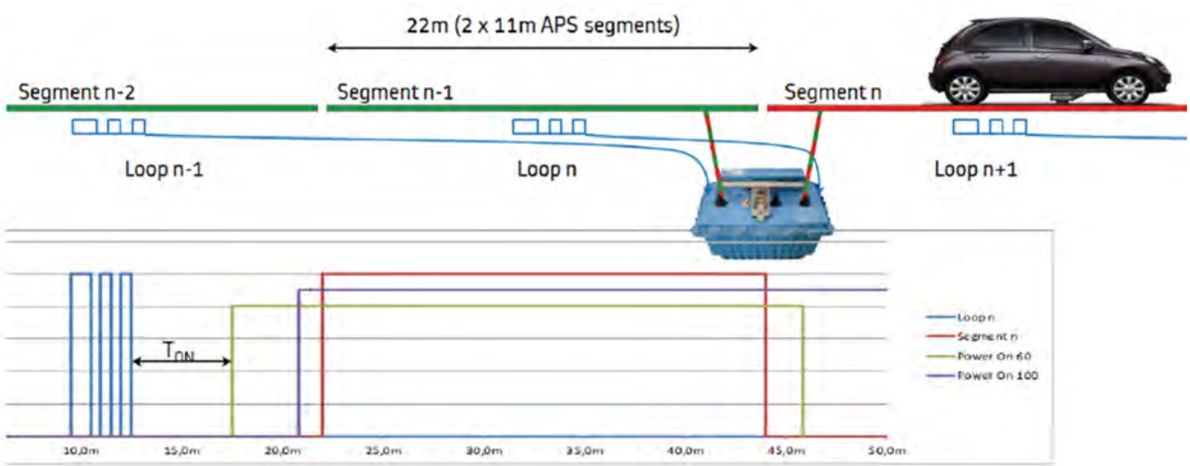

Figure 30 Detection of a ERS vehicle's speed and direction

Figure 26: Detection of vehicle speed

Installation and Maintenance

Alstom's road based APS system is installed into Volvo's test track; the test track is 400m straight road with single electrified lane. The installations of rails are shown in Figure 27, the

process starts by removing asphalt layer of the road surface. Then the foundation of the conductive rail is supported by concrete, the next process is to connect conductive rail to the road side power supply equipment and installation of communications equipment alongside conductive rail. Finally, the road is resurfaced and the conductive rails are aligned with road surface in this process.

Figure 27: installation of conductive rails

The power box (PB) faults are tolerated by the system due to on board autonomy. PB replacement can be scheduled by maintenance. PB faults are identified on the Computerized Aided Maintenance System (CAMS). The conductive ERS must be free of ice or snow in order to allow an electrical contact with the collector shoes, how this can be ensured is a maintenance issue that will be addressed as the project progresses.

4.2 UNPLUGGED Project Solutions

The FP7 UNPLUGGED project aims to investigate how the use of inductive power transfer of Electric Vehicles in urban environments improves the convenience and sustainability of car-based mobility. Note that the UNPLUGGED solutions are primarily intended for static and stationary applications.

The project includes the development and assembly of two wireless power transfer solutions for static and en route applications. The prototype solutions were built and tested in laboratories, however since May 2014, the project partners work on integration of these prototypes into the test vehicles.

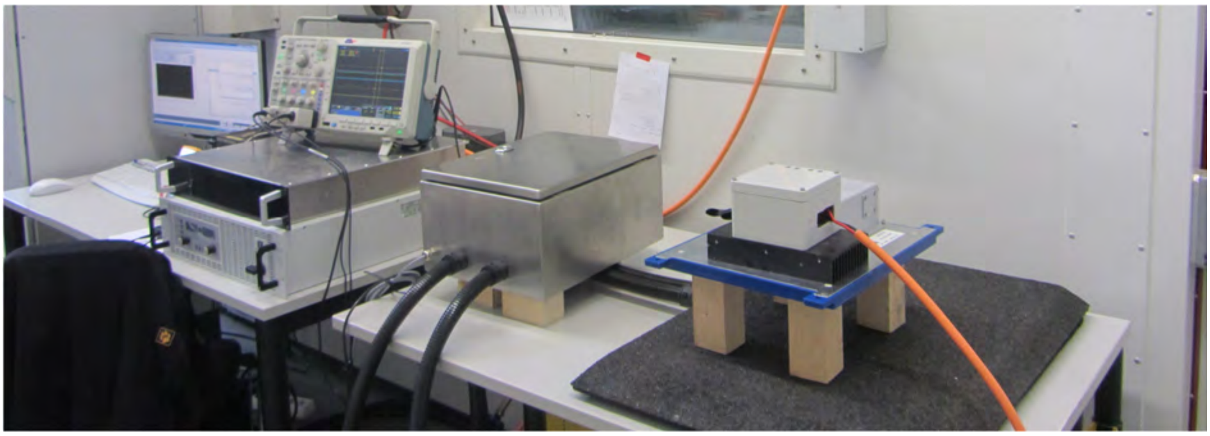

Figure 28: 3.7 kW Prototype

The low power system is a 3.7 kW inductive power transfer solution, this system is designed for light duty vehicles and it operates on single phase with current rate up to 16 A on the primary side.

The high power system is a 50 kW inductive power transfer solution; this system is designed for medium to heavy duty vehicles. The 50kW system consists of two 25 kW coils and it can be scaled up in steps of 25 kW by additional coils. Transfer voltage can be 350 V for cars and light trucks or 700 V for heavy trucks and busses.

The solutions adopt wireless LAN compatible to IEEE 802.11b/g/n, and the data exchange is based on ISO 15118 protocols. Figure 29 shows the whole system diagram of UNPLUGGED inductive power transfer solution. As seen from the diagram the grid provides 700 VAC via distribution network, and power converters switch this voltage to either 350 V, 145 kHz or 700V 20Khz AC wave forms. Wirelessly transferred energy is converted back to the DC on the

vehicle. Wireless communication occurs whilst the vehicle is parked on the primary coils, the vehicle and the infrastructure share following information;

- Request to charge
- State of charge

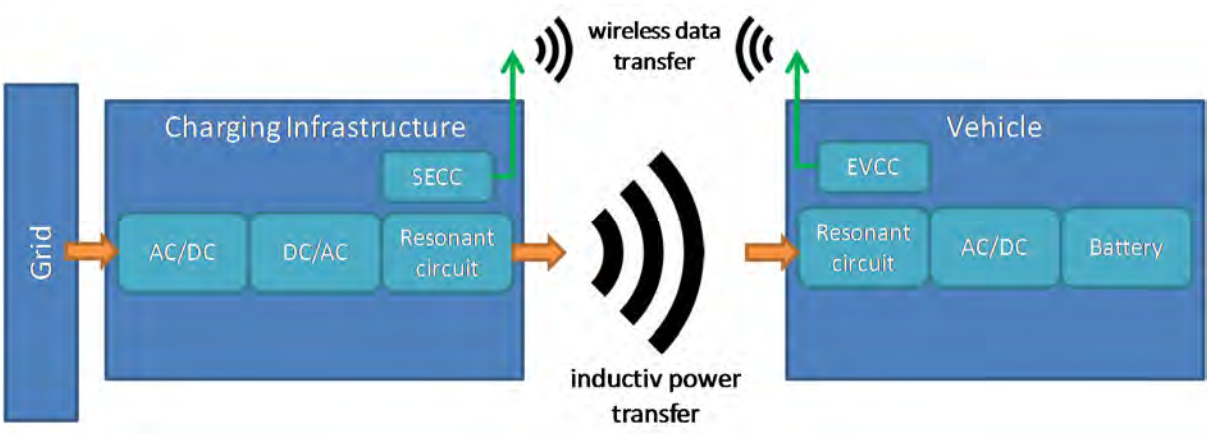

Figure 29: UNPLUGGED Inductive Charger Schematic

Specification

Parameter	Value
TRL Level	Actual - 4: The technology components are developed and validated in laboratory environment Project target - 6: The prototypes will be integrated into vehicles and the functionality will be demonstrated in a relevant environment
Costs	N/A
Foreign object detection	none
Voltage	50 kW System: Primary: 400 V AC, three phase Secondary: up to 700 V DC, 350 V DC used for the demonstrator 3.7 kW System: Primary: 230 V AC, one phase Secondary: 250 V DC
Current	50 kW System:

	Primary: up to 100 A Secondary: 3.7 kW System: Primary: up to 16 A Secondary: 10 A
Power rating and Power Range	50 kW (2 5kW or multiple of 25 kW possible) 3.7 kW
Power Factor	N/A, will comply with regulations
Quality Factor	N/A
Overall System Efficiency	nominal working conditions: 50 kW System: > 90% 3.7 kW System: app. 84%
Operating Frequency	50 kW System: 20-30 kHz 3.7 kW System: 145 kHz
Air gap	50 kW System: 180 to 250 mm 3.7 kW System: up to 170 mm, typical 100 – 130 mm
Effective misalignment tolerance (x,y,z)	50 kW System: 100 mm (x-direction), 130 mm (y-direction) 3.7 kW System: expected 100 mm
Distance between supply feeds	N/A
Communication protocol (ISO 12118, IEC 61851 etc)	Protocol based on ISO 15118
Communication Method (wireless, Bluetooth, etc)	WLAN
EMC, EMF	N/A
EM Exposure	N/A
Harmonics (THD % V & I)	N/A
Over current (cut-off)	N/A
Over Voltage (cut-off)	N/A
Ground Module Dimensions	50 kW System: not yet available 3.7 kW System: 700 x 500 mm

Road side Equipment Dimensions	N/A
On-vehicle equipment Dimensions	50 kW System: not yet available 3.7 kW System: 290 x 330 mm
Ground Module weight	50 kW System: not yet available 3.7 kW System: app. 40 kg
Road side Equipment weight	N/A
On-vehicle equipment weight	50 kW System: not yet available 3.7 kW System: app. 15 kg

Communications

The 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. As one special variant, inductive en-route charging will be investigated thoroughly.

For the developed prototype the V2X Medium range communications area is covered: EV to EVSE communications use the IEEE 802.11b/g/n (2,4Ghz) standard, thus a classic WLAN. ISO15118 standard protocol is used.

In-vehicle communication is based on IEC61851 used in standard conductive charging.

4.3 Other Wireless Dynamic Power Transfer Solutions

Only a single other wireless dynamic solution is considered here, but it is an important one because it is probably the most developed wireless dynamic power solution currently in operation.

4.3.1 Online Electric Vehicle (OLEV):

Korea Advanced Institute of Science and Technology (KAIST) has developed one of the first wireless dynamic power transfer solution system called “Shaped Magnetic Field In Resonance (SMFIR)”, publicly known as OLEV (online electric vehicle). The power transmission loops were installed longitudinally under the road surface in segments; the power is collected and stored in the vehicle via receiver coil and a battery. OLEV buses are actively operational in Seoul Grand Park, KAIST campus, City of Daejeonn (kaist launches first wirelessly charged electric buses in south korea) and city of Gumi (OLEV buses South Korea, 2013).

KAIST has developed six generations of wireless power transfer systems, latest system been 4G which is still in its development, variation between these systems are:

- Air gap
- Efficiency
- Power rail layout
- Pick up design

This study concentrates on most established 3^{+}G system, which is in operation in Seoul Grand Amusement Park, KAIST Campus, Yeosu and first commercial operation in city of Gumi.

KAIST state that approximately 15% (Suh N. , 2011) of the route on Seoul Grand Park were installed with power transfer loops in order to conserve the state of charge (SOC) of the on-board battery.. However, it should be noted that this route is equipped with en route chargers on two of the bus stops. The loops are installed in sections along the road; a section length can be long as 122.5m where each section is divided into number of loop segments, the length of the segments length can range from 2.5m to 24m (Suh I. , 2011). As shown in Figure 30, in the KAIST solution, the length of the loop represents a segment and each section is equipped with an inverter to collect the power from the grid and transform into high frequency wave form.

Figure 30: Power transfer intervals in Seoul Grand Park (Image: KAIST)

Figure 31 illustrates the segmentation of a section, the primary loop is active when the vehicle is located on the segment meanwhile non occupied segments are switched off, inverter size and

capacity is dependent on the power rating of the segment. Based on the same technology KAIST has developed a 60 kHz 400A on track power line for trains. (KAIST, 2012)

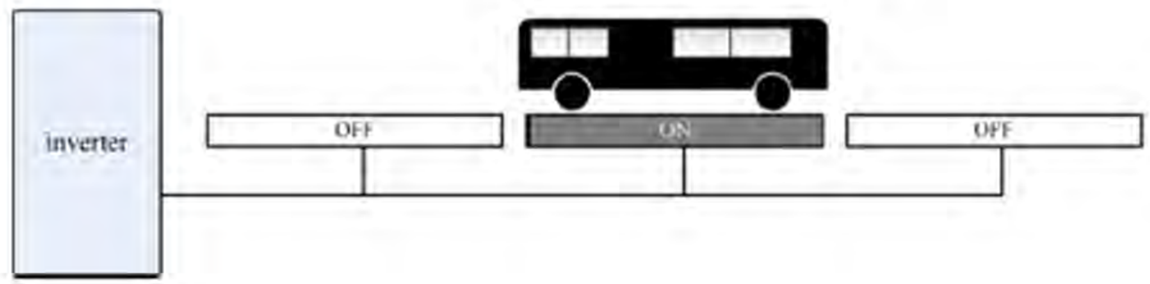

Figure 31: Concept of Segmentation (Image: KAIST)

Figure 32 illustrates the magnetic field between primary loop and the secondary coil, the magnetic poles are used to shape the magnetic field towards the vehicle and the coils are tuned to the resonant frequency in order to maximise the power transfer efficiency.

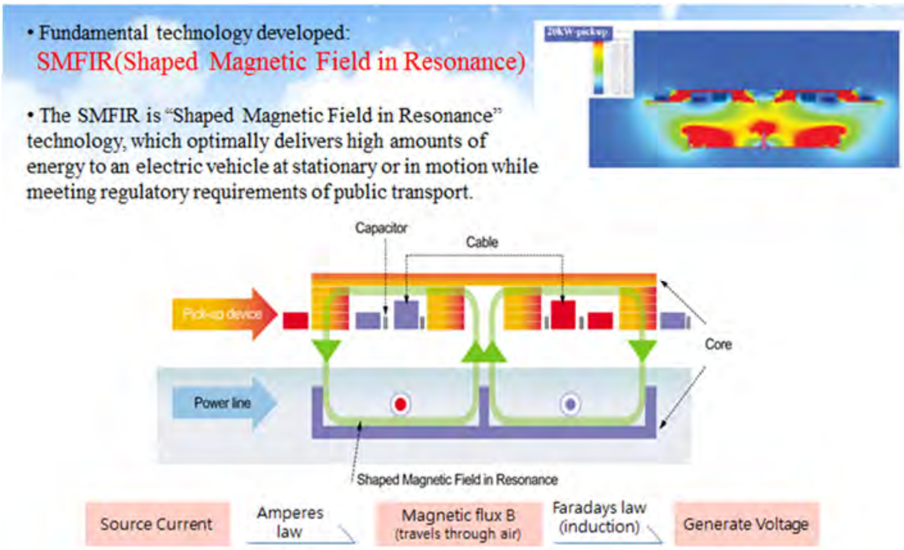

Figure 32: SMFIR diagram (Suh N. , 2011) (Image: KAIST)

Secondary coils can be reshaped to maximise the efficiency depending on the layout of the primary loops. Figure 33 (a) shows the secondary coil design, when the primary loops are based on dual type, whereas Figure 33 (b) shows the secondary coil design when the loops are centred. OLEV adopts EMF cancellation on the secondary coil to reduce the EM exposure to the levels well below 6.25uT (Rim, 2013).

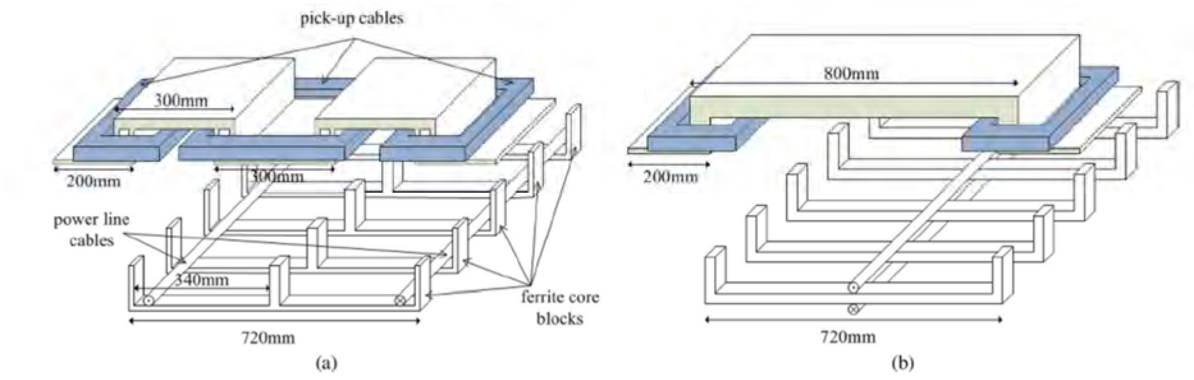

Figure 33: power supply core structure for 20KW pickup module (Image: KAIST)

Specification (Rim, 2013)

Parameter	Value
TRL Level	8 - Technology is proven to work - Actual technology completed and qualified through test and demonstration
Costs	Ca. €800,000/km
Foreign object detection	none
Voltage	3 phase 380V or 440V AC
Current	200A (20kHz)
Power rating and Power Range	Up to 200 kW (current system: 20kW/pickup, 5 pickups per bus)
Quality Factor	Approx. 100
Overall System Efficiency	75% (Dynamic)
Operating Frequency	20 kHz (60kHz successfully tested)
Air gap	Up to 27cm
Effective misalignment tolerance (x,y,z)	20cm
Distance between supply feeds	Up to 122.5
Communication protocol (ISO 12118, IEC 61851 etc) Communication Method (wireless, Bluetooth, etc)	Uses magnetic communication
EMC, EMF	Complies with ICNIRP 2010 1998
EM Exposure	Complies with ICNIRP 2010 1998 (below 6.35uT)

Ground Module Dimensions	2.5m to 24m long loop wires. Field shaping ferrite material.
Road side Equipment Dimensions	200x180x70 cm
On-vehicle equipment Dimensions	80*170*8 cm
On-vehicle equipment weight	80kg
Maximum operation temperature	-30 C to 70C
Friction/skid resistance	Standard road surface

Installation and Maintenance

The ground modules are pre-cast in the factory therefore construction site works begin by excavation of the road The excavation is expected to be 0.8 m wide and approximately 0.5 m deep, followed by installation of pre-fabricated loops and connection to the grid. Figure 34 shows energy flow

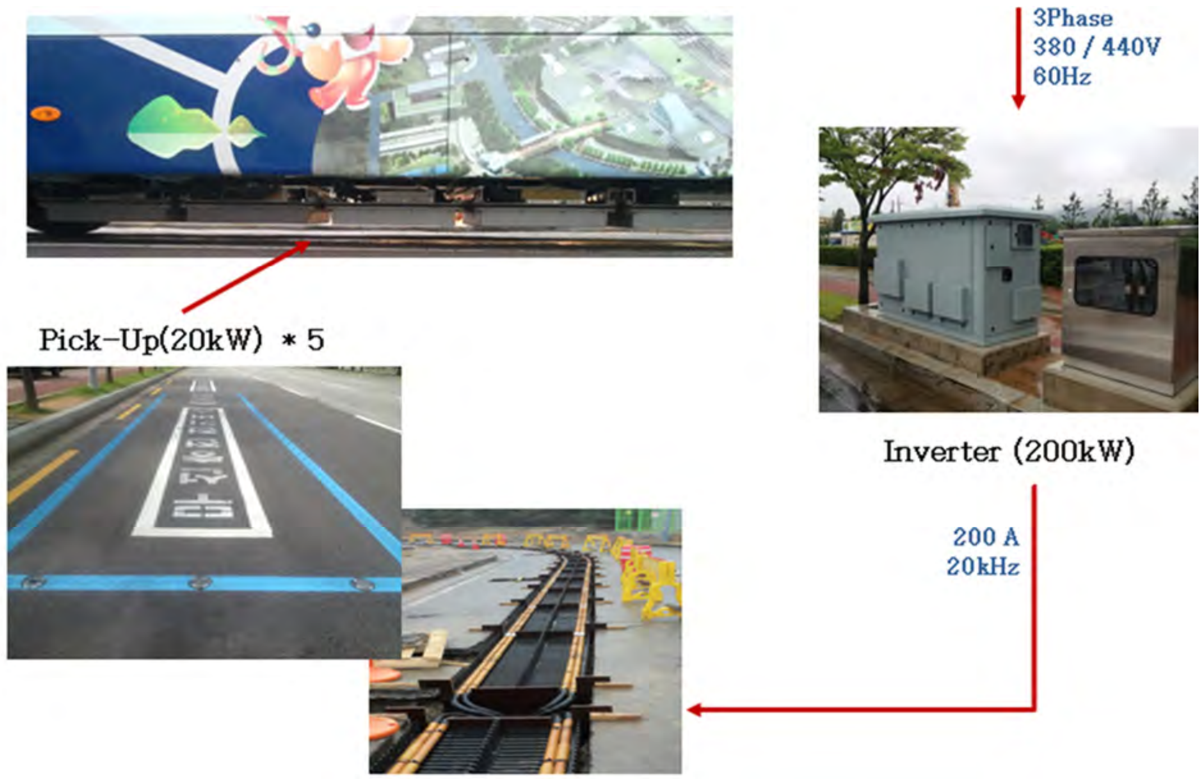

Figure 34: OLEV system (Image: KAIST)

The energy flow follows:

- The road side modules consist of an inverter and the protection equipment. The power is transformed from 3 phase grid voltage to 200A, 20kHz

- The power is transferred from road side to ground module via underground cables, once the ground modules are installed, the final construction process is the road resurfacing.

The Precast loops are built depending on the size a segment, ranging between 2.5m to 24m. Figure 35 shows five stage installation process of each dynamic charger. These processes can be divided into two parts, first part is the manufacture of pre-cast segments and the second part is the installation. The process starts by installing the ferromagnetic cores and loop cables in the cast. Once this process is complete the cast is filled with concrete. The segments are placed in the vaults, and all the segments connected to the road side equipment. The connections between the grid and the road side is been carried out in parallel with the on-road installations, the next procedure is to connect the in-road power transfer equipment to the road side units. . The final process is to resurface the road; there are no specific requirements for road surface in power transfer point of view, as long as it is does not include magnetic material which will distort the magnetic field shape between primary loop and pickup coil.

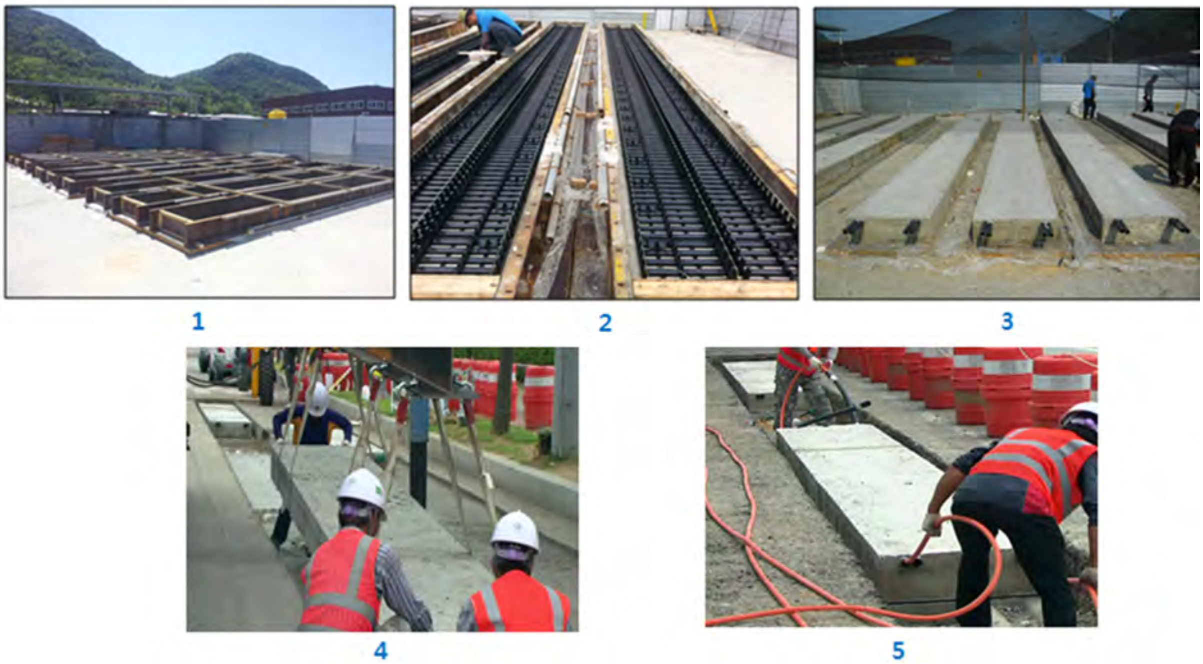

Figure 35: Pre-cast construction and Installation (Image: KAIST)

The system requires very little maintenance, the inverters on the road side equipment will require routine maintenance but ground modules are designed to operate maintenance free within its life time.

Communications

Currently KAIST has no wireless communication, especially linked together with DSRC or WAVE for V2V or V2I application.

However, it is expected that the communication method will not be a roadblock for WPT EV charging application, because the communication technology including ad-hoc V2V are currently developed and demonstrated in ITS separately. The system developers expect that it can be easily incorporated into OLEV system upon project functional requirement.

4.4 Other Wireless Static Power Transfer Solutions

A number of static wireless power transfer solutions have been identified. These are considered below.

4.4.1 Conductix Wampfler IPT:

Conductix Wampfler's Inductive Power Transfer (IPT) operates on wireless resonant inductive power transfer principle. Conductix Wampfler is world's leading supplier of mobile energy and data transmission systems (Conductix, 2014). The IPT system is designed for static and stationary applications.

The system was previously used in factory automation robotics; the system was redesigned to supply power to the electric vehicles. The solution is based on magnetic resonant induction. Conductix only developed the system for opportunistic en-route power transfer for buses, where power transfer only occurs when the vehicle is in stationery position above the primary coil for a short period of time. The Conductix Wampfler solution is currently operational in Genoa, Turin, s'Hertogenbosch and Milton Keynes electric bus projects.

Figure 36 shows the layout of high level wireless inductive power transfer system. AC source represents the power from the grid; the power electronic module transforms the grid parameters to the parameters that are suitable for wireless power transfer at maximum possible efficiency. Final stage of the transfer is the vehicle module; this sub-system re-converts high frequency power to DC power in order to charge on-board battery or providing power directly to the vehicle.

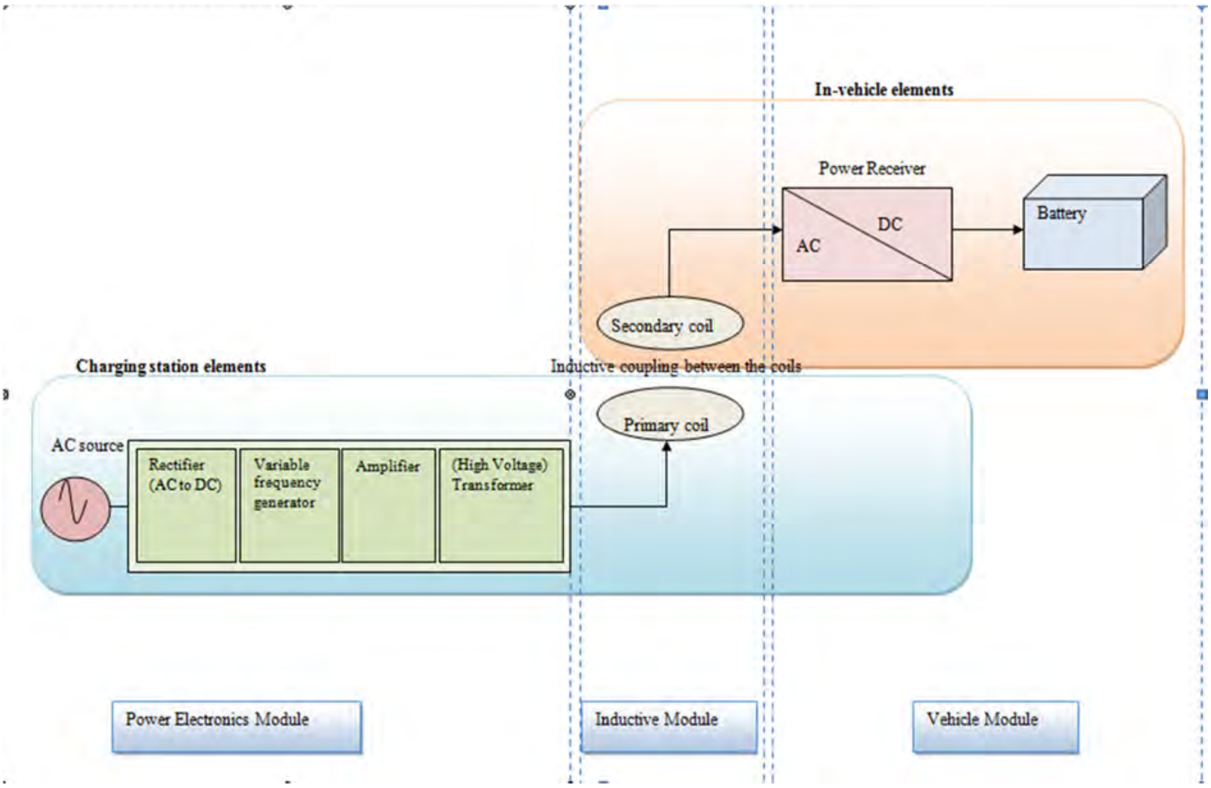

Figure 36: Wireless power Transfer Principle

The IPT charger consists of primary and secondary coils; the primary coil is located level with the road surface. As shown in Figure 37. The ground modules are in flush with the road and each ground module consists of number of coils depending on power transfer rate. Each coil is rated at 30 kW to 50 kW, in this particular case shown in the figure, the ground system contain two modules, each module contains two 30kW primary coils and power electronics to converts 400V AC grid supply to 600V 20kHz capable of transferring 120 kW.

Figure 37: IPT charger

On-vehicle module is located under the vehicle, each pick up coil is rated at 30-50kW and there can be more than one coil on the vehicle, depending on the design and requirements of the vehicle. On-vehicle module is mechanically movable arm platform where secondary coil is lowered to the road surface level to maximise the transfer efficiency and reduce stray field effects. The operation of on-vehicle moveable arm is shown in Figure 38 and Figure 39.

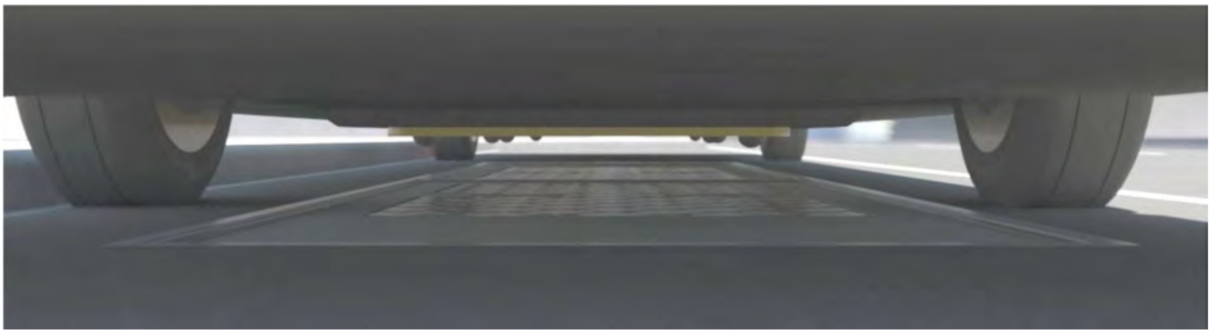

Figure 38: Position of the pickups during non-charge (Conductix Wamplfler, 2014)

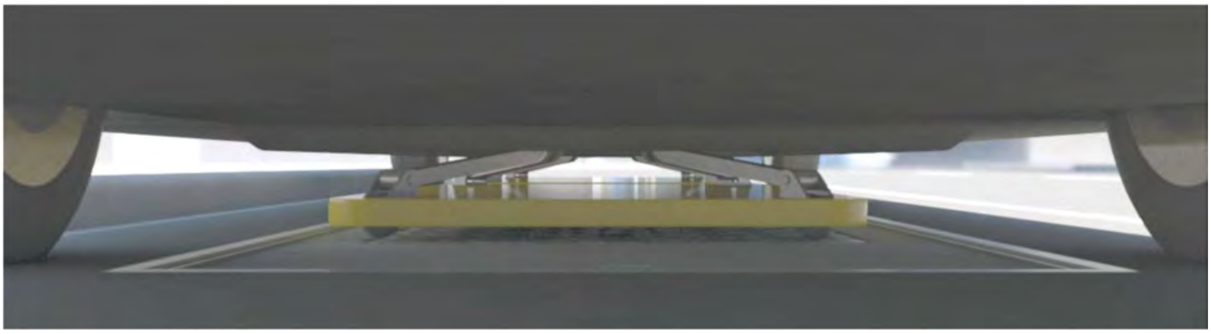

Figure 39: position of the pickups during power transfer (Conductix Wamplfler, 2014)

The road side equipment consists of monitoring unit and cooling system as shown in Figure 40. The power supply cables and cooling pipes are connected to the ground module via underground connections. The monitoring unit contain systems to control and monitor power supply such as circuit breakers and protection equipment. The cooling system pumps cooling liquid between the underground module and storage tank in the cooling system, the primary coil temperature is controlled by liquid cooling method; the cooling liquid is pumped between road side cooling equipment and ground module. The power electronics to convert grid power to high frequency wireless power is located within the underground power transfer units.

Figure 40: Road side power electronics and cooling unit.

Specification *(Conductix Wamplfler, 2014)*

Parameter	Value
TRL Level	9: Actual application of technology is in its final form - Technology proven through

	successful operations
Foreign object detection	N/A
Voltage	Input:400V AC per module Output: 600V DC per module
Current	101 A per module
Power rating and Power Range	120kW – 200 kW(two modules, four coils)
Power Factor	0.92
Overall System Efficiency	93%
Operating Frequency	20kHz
Air gap	4 cm
Effective misalignment tolerance (x,y,z)	4cm, 4cm, 1cm
Distance between supply feeds	N/A
Communication protocol (ISO 12118, IEC 61851 etc)	FHSS
Communication Method (wireless, Bluetooth, etc)	Ethernet, Wireless data transmission
EMC, EMF	Radiates: EN55011 class B Conducted: EN55011 class A1 Immunity: EN 61000-6-2
EM Exposure	ICNIRP 2010
Harmonics (THD % V & I)	IEC EN 61000-3-4 Applies
Over current (cut-off)	10% rated Current
Over Voltage (cut-off)	10% rated Voltage
Ground Module Dimensions	3.1x1.55x1.03m
Road side Equipment Dimensions	1.9x2x0.5m
On-vehicle equipment Dimensions	1.023x0.875x0.06 m
Ground Module weight	Approx. 8000kg
On-vehicle equipment weight	70kg coil + 22.5kg power electronics
Distance between feeder points	Single unit
Operation temperature	-20 ^{0}C to +45 ^{0}C
Vibrations	3mm at 2-9Hz 0,5h at 9-200Hz 8g max shock in operation
Structural integrity (max load)	400 kN
Friction/skid resistance	DIN 51130:2009-5

Installation and Maintenance

The equipment is installed on the road surface level by concealing entire ground module in flush with the road surface. Figure 41 shows the high level installation process for the IPT chargers;

1. Excavation of the road surface
2. Installation of main ground module
3. Stabilising the ground module foundation

4. Connection of road side equipment to the grid supply and connection of power and cooling equipment to the ground module, these tasks also require excavation for routing the cables and pipes.
5. Resurfacing of the road surface.

Figure 41: installation of IPT ground module

The installation of a primary module can take up to 2 – 3 days depending on environmental conditions. The solution does not require any maintenance in its life time other than replacing worn out primary module surface..

4.4.2 Plugless Power

Plugless power is a Level 2 (208 - 240 volt, single phase, maximum current of 32 amps) EV power transfer system (240V) developed by Evatran in partnership with Bosch. Plugless is the first commercially available wireless EV power transfer system, currently offered to the Chevrolet volt and Nissan Leaf customers, the cost of a power transfer unit can be low as $3000 (£1920) (Plugless Power).

Plugless power is static resonant inductive power transfer solution, the system is designed for household use therefore it is rated to supply power to the vehicle at 3.3kW. The system consists of wall mounted power electronics unit, primary coil pack and secondary on-vehicle coil. The solution has an automatic foreign object detection and auto switch off if any ferrous or metallic material is present within effective range.

Specification

Parameter	Value
TRL Level	9: Actual application of technology is in its final form - Technology proven through successful operations.
Costs	€ 2370
Foreign object detection	Yes
Voltage	Supply: 208-240V
Current	30 A rated
Power rating and Power Range	3.3kW
Power Factor	0.65
Overall System Efficiency	87%
Operating Frequency	19.5kHz
Air gap	10cm
Effective misalignment tolerance (x,y,z)	
Distance between supply feeds	Single unit connected to mains
Harmonics (THD % V & I)	V THD: 4% I THD: 112%
Ground Module Dimensions	6.35x55.9x47cm
Wall mounted Equipment Dimensions	49x23.9x12.7cm
On-vehicle equipment Dimensions	46.4x76.2x12.7 cm
Ground Module weight	16kg total weight
Maximum operation temperature	-18 0C to 50 0C
Structural integrity (max load)	680 kg

(Plugless) (Idaho National Laboratory, 2013)

Installation and Maintenance

The solution requires installation of on-vehicle unit to the battery and connection of wall mounted power electronics unit to the house electricity supply. The primary coil is a standalone device which doesn’t have to be embedded onto the ground surface.

4.4.3 WiTricity

WiTricity Corp was formed to commercialise the wireless electricity transfer system developed in MIT (Massachusetts Institute of technology) (WiTricity, 2014) in 2007 by team of physicists. WiTricity is specialised in development of wireless power transfer system for various products such as consumer electronics, industrial, transportation and medical and military purposes. WiTricity has provided their solution to numerous OEMs and vehicle manufacturers such as Delphi, Toyota, Audi and Mitsubishi.

The company developed WiT-3300 to wirelessly power transfer electric vehicles, the solution operates on resonant magnetic coupling principles and it only transfers power when the vehicle is stationary. The system consists of on vehicle secondary coil, and rectifier assembly on the vehicle, and a primary source coil unit and RF amplifier assembly off the vehicle. The solution can be powered by household mains power supply, the RF amplifier assembly converts the AC mains to DC then invert the DC into 145 kHz RF voltage waveform for efficient power transfer through the air gap, the secondary coils collect the power and converts to direct current to charge the vehicle battery (Witricity Corporation, 2013). In order to match the source and collector coil's frequency WiTricity uses an impedance matching network.

WiTricity have been developing wireless power transfer systems for various industries but even though wireless EV charger is proven to be functional it is not yet commercially available; however Toyota has licenced the WiTricity wireless system and started trials and verification tests for their Electric and Hybrid models (EV Fleet World, 2014). The system baseline system is connected to the grid via household single phase supply, but WiTricity stated that their solution can be connected to the higher voltage levels depending on OEM or Automotive manufacturer's requirements.

Figure 42: primary and secondary coil (Witricity Datasheet, 2013)

Specification

Parameter	Value
TRL Level	8
Costs	Price is set by the customer (OEM and Tier 1 suppliers
Foreign object detection	No
Voltage	Input: 230V ac Output: 350-400 VDC
Current	10A
Power rating and Power Range	300-3300 W
Overall System Efficiency	90%
Operating Frequency	145kHz
Air gap	18cm
Effective misalignment tolerance (x,y,z)	10cm (front to back axis) 20cm (side to side
Distance between supply feeds	N/A
Ground Module Dimensions	0.5x0.5x0.0375m
Road side Equipment Dimensions	0.22x0.33x0.13m

On-vehicle equipment Dimensions	0.5x0.5x0.0375m
Ground Module weight	12.5kg
Road side Equipment weight	4.2kg
On-vehicle equipment weight	16.1kg

(Witricity Datasheet, 2013) (Witricity Corporation, 2013)

Installation and Maintenance

The solution requires installation of on-vehicle unit to the battery and the wall mounted power electronics can be plugged in to the mains plug. The primary coil is standalone device which doesn't have to be embedded onto the ground surface.

4.5 Other Conductive Power Transfer Solutions

In this section we consider solutions which transfer power using conductive techniques. These solutions tend to be developed from overhead and third-rail based systems as used on rail and metro systems for dynamic solutions, or use a form of rapid power connection for static systems.

4.5.1 Siemens eHighway (SCANIA) (dynamic)

Siemens e-Highway system is road electrification project similar to rail electrification where power transferred from overhead conductors to the vehicle's on-board traction or battery. The system is adaptation of railway electrification but unlike rail systems, the vehicle overhead systems have more than one contact conductor. This is required because rail electrification uses the rail track as a ground conductor, however a road vehicle has rubber wheels and the road is asphalt, therefore requiring a second conductor as a ground to complete the circuit. The road side equipment consists of transformers and protection devices, these devices can be attached to the masts to reduce clutter but this is dependent on the size and the weight of the equipment. The overhead wires collect power from substations; the substations contain a medium voltage DC switching system, a power transformer, a rectifier (12 diode array) and a controlled inverter for regenerative breaking (Siemens ehighways, 2012) . Siemens has tested the eHighway system in a test track and plans to start a pilot project for the ports of Los Angeles and Long Beach to connect cargo centres (Scania and Siemens to develop heavy-duty hybrid vehicles with trolley-assist; enabling the eHighway, 2013)

Specification

Parameter	Value
TRL Level	7-8
Costs	£930 000 per km (Sanna Anderson, 2013)
Foreign object detection	
Voltage	750 VDC
Overall System Efficiency	90-97%
Maximum Speed	90km/h
Overhead line clearance from the ground	Approx. 5m
Conductive wire clearance from the mast (conductive specific)	N/A
Distance between two masts (conductive specific)	40-50

Installation and Maintenance

Installation and maintenance of an eHighway system can be divided into two sections; grid to road side electrical installations and on-road installation of masts and catenary installations. The installation procedures can be very similar to the rail, but the road closures during on-road electrification should be considered.

Communications

Siemens has developed and demonstrated a conductive dynamic charging system for heavy vehicles where GPRS is used to communicate between the vehicle's OBU (on-board unit) and the OCC (operation & control centre).

4.5.2 Elways (dynamic)

Elways develops dynamic power transfer solutions, the company was founded in 2009 in Solna, Sweden.. Elways has tested their conductive power transfer system in numerous severe weather conditions. The system is tested using a car with a dummy load. This load was varied from the power requirement for a car at 90 km/h up to the power requirement by a truck weighting 60 tons and moving at 80 km/h (Elways). Figure 43 shows the Elways conductive energy transfer system with dummy load (halogen lamp).

Figure 43: Elways System (Image: Elways)

Figure 44 and Figure 45 shows two parallel segmented power rails embedded on the road surface, the conductive rails are connected to the power control electronics to energise the rails when the vehicle movable arm is in contact with the rails. The power control electronics collect the power from the road side transformer which is connected to the main grids (Elways).

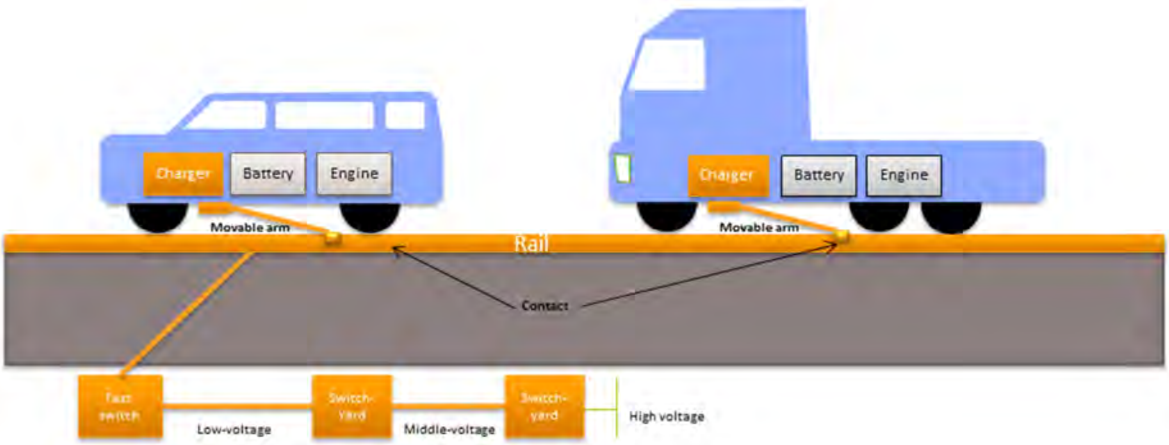

Figure 44: Elways conductive power transfer solution (Image: Elways)

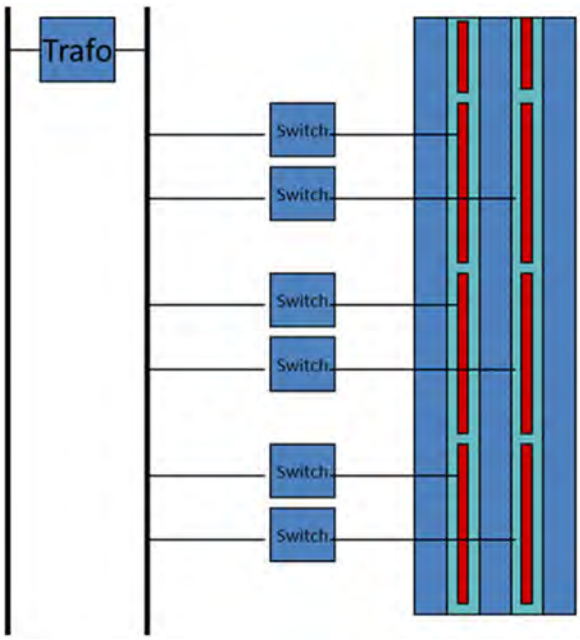

Figure 45: Grid to Rail Connection diagram (Image: Elways)

Mainly for safety reasons the conductors are in 50 to 100 meter sections and each segment within that section is only energized when the correct vehicle is located on top of that specific segment. The moveable arm is capable of automatically repositioning itself, therefore, as long as the vehicle is above the rails, power can be transferred from the rails to the vehicle via moveable arm.

The power control unit on the vehicle is designed to operate in multiple power supply modes such as charge the battery, directly supply power to the traction motor or both. The switches are connected to 33 kV cable running along the roadside; The road side cables are connected to exit point of 133 kV to 33 kV transformer, these transformers receive power from the grid and they can be located up to every 50km depending on the transformer rating and the demand.

Elways has carried out over 70 tests in all weather conditions, including temperatures low as -14 ^{0}C. During the testing, the transferred energy was consumed on dummy loads such as heating elements or halogen lamps. The load was set up to ensure power transfer simulates the demand from the real world driving conditions.

Specification

Parameter	**Value**
TRL Level	7-8
Costs	Approx. €4.66m/km

Foreign object detection	Designed to withstand collation with objects inside the track. Bigger objects on the surface of the road could be detected by collision warning systems
Voltage	Between 400 and 800 V
Current	Up to 250 A
Power rating and Power Range	Up to 200 kW
Power Factor	As wanted- depending specification
Quality Factor	As wanted- depending specification
Overall System Efficiency	>95 %
Distance between supply feeds	grid
Communication protocol (ISO 12118, IEC 61851 etc.)	Not chosen yet
Communication Method (wireless, Bluetooth, etc.)	Not chosen yet
EMC, EMF	Low- depending on what is specified
EM Exposure	Comparable to any ac cable
Harmonics (THD % V & I)	As wanted- depending specification
Over current (cut-off)	As normal distribution systems
Over Voltage (cut-off)	As normal distribution systems
Ground Module Dimensions	Transformers and switch yards are installed between the medium voltage cable and the low voltage cable every 1 km. The dimensions of this outdoor station is around 2 meters wide, 3 m long and 2.5 m high
Road side Equipment Dimensions	Every 50 to 100 meters switches are installed to connect the sections of the rail. These boxes are located under ground
On-vehicle equipment Dimensions	Moveable arm can be fitted inside the bumper. A control box is required to control the moveable arm.

Installation and Maintenance

The high level installation process consists of excavation of strip of the road where conductive rails will be installed. locate the conductor rails and cabling into the excavation and final process

is the re surfacing of the road as shown in Figure 46 The installation also requires excavation of addition vaults every 50-100 metres, where switching equipment and connection cables are located.

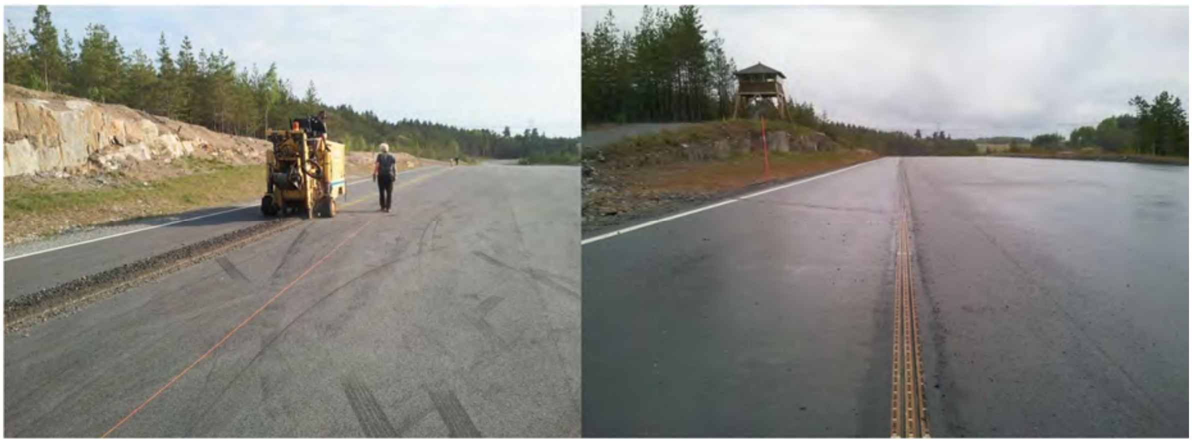

Figure 46: a) excavation of existing asphalt surface, b)completed electrified road

The system is designed to operate for 20 years, however, the contact points on the vehicle need to be replaced every 10,000km due to wear and tear.

Communications

The conductive dynamic EV charging system that Elways has developed currently has no communications and is focused on power transfer.

4.5.3 Opbrid Busbaar (static)

Opbrid SL was founded in 2009 in Granada, Spain, with the sole aim of providing automatic conductive power transfer stations for electric and hybrid urban buses. The company has introduced the Orpbrid Bůsbaar — an overhead, pantograph-based fast-power transfer station for buses. The system consists of two parts, an movable overhead rail platform and an on-vehicle collector system. The power transfer starts when the bus parks at Busbaar power transfer platform. The mechanical rail platform moves down and contacts two pantographs on top of the bus. The overhead rail platform consists of two 6 metre rails separated by an insulator. One of the rails is supply and the other is return. The system provides static high power transfer to the on-vehicle battery via a Shaefer Charger.

The first rapid charge system was successfully installed Gothenburg and Umea, Sweden, the power transfer stations were installed on each end of the bus route to power transfer three hybrid buses for 5-8 minutes during turnover period (Opbrid Bůsbaar Begins Charging Volvo Plug-In Hybrid Buses in Gothenburg, Sweden).

The main advantages compared with inductive static solutions are;

- Higher power transfer, the system can transfer power up to 240 kW
- Higher efficiency as the inefficiencies caused by the air gap in wireless systems is eliminated due to its conductive connection.
- Ease of construction, the system does not require excavation of the road.
- Ease of docking, the 6 metre rails transfer are perpendicular to collector rails located on the roof of the bus, therefore as long as vehicle is under the rails, the power can be transferred at maximum rate.

Specification

Parameter	**Value**
TRL Level	8
Costs	150000 – 20000 (euros)
Voltage	400V (three phase)
Current	700A
Power rating and Power Range	100kW -240kW
Overall System Efficiency	90%
Operating Frequency	N/A
Air gap	N/A
Effective misalignment tolerance (x,y,z)	N/A
Distance between supply feeds	Single unit
Communication Method (wireless, Bluetooth, etc)	3G connection with the grid operator
Harmonics (THD % V & I)	Not known
Over current (cut-off)	100% of nominal current
On-vehicle equipment weight	65kg
Distance between feeder points	Not known
Coil/ loop life time	Not known
Maximum operation temperature	-25 0C to 55 0C

Installation and Maintenance

Installation process for Orpid Busbaar;

1. Connection of road side transformation and protection equipment to the grid,
2. Construct the platform of moveable rail platform
3. On vehicle installation of pantograph, charger and connection of the charger to the on-vehicle battery.

4.6 Oprid promises 30 year design life on any weather. The power transfer station requires very little maintenance other than annual periodic inspection (Opbrid Bůsbaar Begins Charging Volvo Plug-In Hybrid Buses in Gothenburg, Sweden).Research Projects

The purpose of this section is to focus on research projects addressing vehicle charging. A number of research projects have been carried out by universities and research institutions to increase electric vehicle range in order to minimise range anxiety experienced by users, which is believed to slows the take up of EVs. The increase in vehicle power transfer projects over the last five years shows the increasing interest in this field.

The University of Auckland and Massachusetts Institute of Technology have already developed power transfer systems and formed spin off companies such as HaloIPT and WiTricity. More recently the Wave spin off from Utah aims to commercialise their own wireless power transfer system.

4.6.1 Oak Ridge National Laboratory (ORNL) Dynamic Power transfer

Oak Ridge National Laboratory (ORNL) is the largest multi program, science and energy laboratory in the US, funded mainly by United States Department of Energy (DOE). ORNL Partners with universities and the industry in energy, advanced materials, manufacturing, security and physics (Oak Ridge National Laboratory).

ORNL has carried out research on static and dynamic inductive power transfer; the projects aim to develop deep knowledge in coupling coil design essentials, power flow regulations, leakage field minimisation, misalignment tolerance and interoperability (Dr. John M. Miller, 2013)

ORNL has developed dynamic wireless power system in a laboratory test environment. The system consists of six ground embedded primary coils and a GEM electric vehicle integrated with secondary coil to collect the energy. The solution is based on dynamic resonant inductive power transfer with power transfer rate of 10kW at 22 kHz achieving efficiencies up to 85%.

The system consists of 6 wireless primary coils divided into three, two coil segments. Two coils are connected in series and a single grid side unit is used to drive the coils depending on the

vehicles relative position, which is determined by radio communication systems, with roadway optical sensors as a backup verification.

Figure 47 shows the schematic diagram for dynamic power transfer solution. The stationary side of the WPT system consists of a utility grid, an active front-end rectifier with power factor correction, a high frequency H-bridge inverter, and two series connected transmit coils with their series resonant tuning capacitor. The vehicle side of the system includes a receive coil mounted underneath of the vehicle with a parallel resonant tuning capacitor, a diode bridge rectifier with a DC filtering capacitor, and the vehicle battery. ORNL aims use air cooling on the vehicle side and liquid cooling for the stationery equipment.

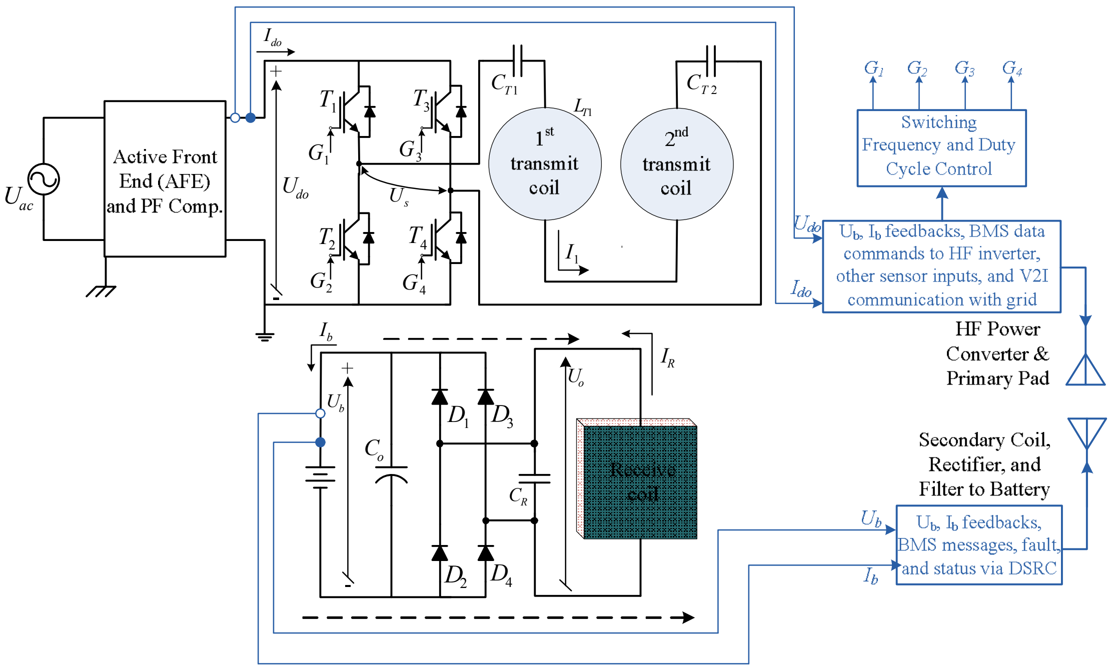

Figure 47: Dynamic power transfer system of each segment (Image: ORNL)

ORNL has built one in-motion wireless power transfer demonstration.. There are also several other parallel projects on stationary wireless power transfer developments and deployments.

Specification:

Parameter	Value
TRL Level	6
Costs	Test system cost $10,000 (equipment only)
Foreign object detection	Optical and visual sensing system is used to detect the objects between the coils.
Voltage	220V single phase

Current	45A
Power rating and Power Range	20kW (target up to 260kW within three years)
Power Factor	0.98
Overall System Efficiency	88 %
Operating Frequency	22kHz, 85kHz or 144kHz
Air gap	16 cm
Effective misalignment tolerance (x,y,z)	12cm
EM Exposure	B=0.5847uT E=3.53 V/m
Harmonics (THD % V & I)	Current harmonics <4%
Ground Module Dimensions	60cm x 60cm coil
Coil/ loop life time	20 years
Maximum operation temperature	120 ^{0}C
Coil cable	Litz wire

Installation and Maintenance

The system is currently in development, however ORNL aims to develop a successfully system that will be embedded under the road surface with road side power electronics. The projection for life time of the equipment is 20 years.

4.6.2 University of British Columbia – Magneto Dynamic Coupling

Magneto dynamic coupling (MDC) is a low frequency wireless power transfer method developed by University of British Columbia. The solution is based on principle of magnetic gearing, where two rotating permanent magnets are coupled, therefore rotation of primary magnet causes rotating magnetic field around second magnet which in return starts to rotate as illustrated in Figure 48 (Green Car Congress, 2012) (Wireless Charging). The system can operate at lower frequencies therefore it reduces the exposure to Electromagnetic waves and stray fields. The successful research projects in MDC led to the UBC spin off company Elix Wireless Power transfer systems.

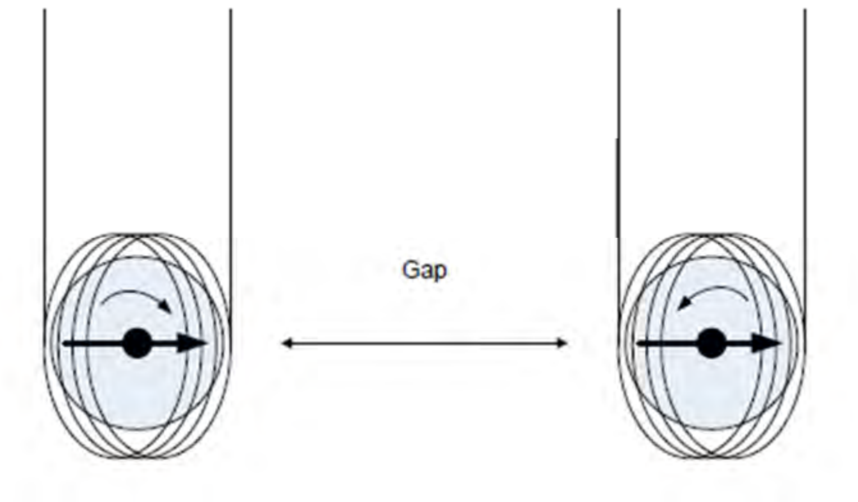

Figure 48: magneto dynamic coupling (Image: Elix)

The solution operates at 150Hz (9000rpm) transferring power at 1.6kW with 15cm air gap at 80% efficiency. The systems main advantage is low frequency operation which eliminates complex control and communication systems, electromagnetic interference and exposure.

The main coupling mechanism is two synchronised permanents magnets on transfer and receiving ends. Transmitting magnet applies torque to the secondary magnet; mechanical rotation of secondary permanent magnet generates electricity. Voltage generated is dependent on magnetic strength, size, motor revolution, and winding arrangement. The tests showed the system was capable of transferring 1kW at 15cm air gap with a Cylinder magnet with 5cm diameter and 10cm length.

4.6.3 University of Stanford Wireless Power Transfer for Moving Vehicles

This project analysed a highly efficient wireless charger that can transfer energy over several feet. The future objective of the research team is to develop the existing system to charge the vehicle in-motion (Vehicle Wireless Charging, 2012). The system works on a resonant coupling principle of magnetic induction.

4.6.4 UTAH state university- WAVE IPT

WAVE IPT Inc. is a Utah State University Spin-off Company formed in 2011; the company aims to provide wireless power transfer solution to electric vehicles. WAVE IPT has already developed 5kW, 25kW and 50kW systems. The 50kW system operates at input voltage of 480V 3 phases, Wireless power is transferred at 23.4 kHz with an efficiency of 90% using a 17.5cm

air gap (Wu, 2012). The output voltage on 90cm diameter coil is 330-390VDC, each coil weighing approximately 27kg.

WAVE IPT's Existing projects are based on opportunistic power transfer of electric buses, the projects are;

- Aggie bus: Wave and Utah state university developed first solid state 25kW wireless energy transfer chargers. The project started in spring of 2013 and the energy is transferred to the bus by two wireless chargers.
- Monterey Trolley: the project was with partnership with Monterey-Salinas Transit, the diesel buses were replaced with electric buses powered by 50kW wireless chargers. The route is 4.5 miles long and the bus charges for 10 minutes from a single charger.
- Utah Transit Authority: This project features fully electric buses operating in University of Utah campus. The route is 1.6 miles where the vehicles are charged from single 50kW for 5 minutes.
- Long Beach Transit's Passport Route: This project consists of wireless power transfer 10 electric buses on a bus route with 50kW chargers. The route is 8.6miles and the buses charge for 10-20 minutes from two chargers.

4.6.5 North Carolina State University

North Carolina State University researchers have demonstrated dynamic wireless power transfer methods in a laboratory environment. Their system is named "multi-resonant IPT" and it uses two or more harmonically related frequencies rather than single frequency transfer, in this case fundamental and third harmonic frequency were used to transfer power. The project aims power the vehicle for 300 miles, using battery on one vehicle and capacitor on the other to store the energy from the wireless charger. The dynamic power transfer simulations were carried out on ADVISOR vehicle simulator, a software model to calculate energy requirements of vehicles in specific scenarios.

Multi resonant IPT system operates by allowing lower harmonic currents to be transferred as energy to the secondary coil; multiple frequency transfer was achieved by using inductor-capacitor ladder circuits (Pantic, Zeljko, 2013). This system aims to increase the power transfer rate and efficiency by using multiple but low frequencies rather than single high frequency. the multi-frequency solution has potential to charge more than one vehicle within a power transfer segment if their secondary coils are tuned to different frequency.

The test system is based on 500W 10 kHz solution, at 100V,. While the downside of the system is the low efficiency (75%), the results have shown that even though reducing the transfer

frequency in order to improve the efficiency, this is cancelled out by introduction of third harmonics as supply current. It is believed however with optimisation of the components the solution could achieve 90% efficiency.

4.6.6 University of California, Berkeley:

Roadway Powered Electric Vehicle Project (RPEV), Track Construction and Testing Program Phase 3D research aims to investigate the construction of the on road power transfer and test dynamically powered electric vehicles and determine the technical viability of road powered electric vehicles (RPEV) (California PATH Research Paper, 1994). The research was carried out by University of California in 1994, as part of wider program, Partners for Advanced Transportation Technology (PATH) formed in 1986 with a mission to develop solutions to the problems of California's surface transportation systems (About PATH).

The RPEV system works on magnetic induction coupling where energy transferred from source coil under the road surface to the secondary coil located under the vehicle. The pickup coils are located on movable platform, the platform aims to minimise the air gap between pickup coil and can be lowered to the 2.5cm above road surface. The dimensions of the pickup coil were 4.3m x 0.97m, made from 52 cores sized at 0.48x0.15m and each core consists of 75 laminations.

The power transfer rate is at maximum when primary and secondary coils are aligned therefore steering assistance systems were installed in the vehicle to aid the driver to align the coils while driving. Induction loops were used to detect the vehicle on each segment, the inductive loops were connected to the loop detector and pre-empt detectors which recognise and identify the ID transmitted from the vehicle and send switch on signal to the primary coil control unit.

UC has built a test track of 210 metres in length with 60 metres electrified road in Richmond Field Station to test the technology and construction methods. UC performed series of tests on vehicle control equipment and subsurface primary modules to test for functionality, reliability and safety. The test concluded that the solution does provide power to the vehicle while it is in motion. However there are areas for improvement such as reduction in size and weight, improved efficiency and reduced environmental impacts such as EM exposure.

Specification

Parameter	Value
TRL Level	6
Costs	Up to $1.22m Pickup= $27k, road module= $277k (not

	including standard power conditioning units and construction costs)
Foreign object detection	Not known
Voltage	Input: 460V 3 phase Output: 550V
Current	Roadway: 1200A Output: 350A
Power rating and Power Range	200kW
Power Factor	Not known
Quality Factor	Not known
Overall System Efficiency	60% (existing solution)
Operating Frequency	400Hz
Air gap	2.5- 8cm
Communication protocol (ISO 12118, IEC 61851 etc)	9 bit codes at carrier frequency is 375 KHz
Over current (cut-off)	2000
Over Voltage (cut-off)	600
Ground Module Dimensions	2.8x0.51x0.11 m per inductive loop (two loops side by side)
Road side Equipment Dimensions	Two cabinets (0.7x2.1x0.7m and 1.7x1.5x0.7m) note: measurements are estimates
On-vehicle equipment Dimensions	4.36x1m (coil dimension: 0.15x0.5m)
Ground Module weight	409kg
On-vehicle equipment weight	395kg
Distance between feeder points	11.5metres
Coil/ loop life time	30 years

The secondary coil and the primary loops were made from aluminium as it is cheaper and lighter when compared with copper. The cores were made from silicon steel due to its low cost, good performance and ease of fabrication. The aluminium cores were coated by dipping into liquid plastic to protect from the corrosion. The on-board and roadway used liquid cooling systems, roadway unit used Ethylene glycol to protect the equipment.

Installation and Maintenance

A test track, length of 210 metres with 60 metre electrified road was built in Richmond Field Station. 60 metre electrified section was divided into five 11.5 m segments as well as two bus stop chargers for static energy transfer. Inductive coil segments were buried below the road surface and vaults were used to run electrical connections between segments, each segment consist of 15 aluminium cable (approximately 17mm conductor diameter and 20mm overall diameter) placed in three rows of five, and the length of the cables was limited by the length of the segments.

The roadway inductor module consists of core modules and the conductors, the modules are approx. 3m x 0.5 m, and are placed in the vaults at the end of segments just deep enough for the top of the core modules to be at the surface of the roadway Each module represents only one side of the inductive loop so two modules are placed side by side. The construction of 210m road took approximately five months, Installation stage and time is given below;

1. Remove existing road surface (1 week)
2. Construct troughs for core modules (7 weeks)
3. Build sub surface vaults (1 week)
4. Reroute drainage and any existing sub surface infrastructure (1 week)
5. Grading and paving (4 weeks)
6. Bury detector loops (few days)
7. Place core modules (3days)
8. Installation of conductors
9. Seal the ends of the end of the conductors on vault entrance.
10. Pour polyester/sand mixture over the conductors
11. Connection of conductors

4.6.7 IAV induction charger

IAV (Ingenieurgesellschaft Auto und Verkehr) is an engineering company in the automotive industry based in Germany. IAV designs powertrains electronics and vehicle development (Wikipedia). In 2009 IAV submitted a patent for in-road electric vehicle chargers; the solution aims to provide energy to the vehicle wirelessly using resonant magnetic induction principles.

It should be noted IAV has not the supplier power transfer system, the company works with partners in the industry to develop wireless power transfer units that suits their needs and requirements.

4.6.8 Inverto

Inverto has been working on inductive power transfer systems for 10 years. They were the supplier of a static charger solution for "Continuous Electric Drive" project led by Flanders drive. The system operates at 240VAC mains supply, the power transfer rate is 3.6 kW and efficiency up to 90%. This system is designed to operate from standard mains plug in the house. The power transfer occurs at frequencies as high as 145 kHz, however the EM exposure is reported to be below ICNIRP guideline limit of 6.25 uT.

Specification

Parameter	Value
Voltage	240 Vac
Power rating and Power Range	3.6 kW
Overall System Efficiency	90%
Operating Frequency	125 – 145 kHz
Effective misalignment tolerance (x,y,z)	5cm, 10cm, 3 cm
EM Exposure	Meet ICNIRP 2010 guideline <6.25uT
On-vehicle equipment Dimensions	0.8x0.6x0.03 m
On-vehicle equipment weight	25 kg

4.6.9 Capacitive Power transfer

Capacitive power transfer uses capacitive plates on primary and secondary side to transfer power wirelessly by coupling electric field between transmitter and receiver (Mitchell Kline, 2011). The main benefits of the capacitive power transfer are low electromagnetic radiation, higher positioning flexibility and less heat generation due to high-voltage low current coupling (Murata Manufacturing Co, 2011) (Kline, 2010). However there is very little understanding of this system and it is difficult to transfer high power due to small capacitance of the capacitive coupling through the air, when compared to the magnetic coupling (Funato, Chiku, & Harakawa, 2012).

The capacitive power transfer is still at research level however Murata Manufacturing Co. Ltd managed to mass produce capacitive power transfer modules capable of transmitting 10W, this system can be used to charge consumer electronics products such as laptops, tablets and

smartphones (Murata). Murata Co. Ltd has been granted a patent for their capacitive power transfer technology in the USA in 2012.

Capacitive power transfer is currently used at low power application below EV requirements, however electric vehicle on electrified roadway project carried out by Toyohashi University of technology managed to transfer 50-60W with 80% efficiency from concrete to the car wheel (Japanese researchers send electricity through concrete to car wheels). The solution is capable of transferring power over 8 cm of concrete but the power transfer has to be increased by factor of 100 in order to provide sufficient power to an electric vehicle (Japanese Students Unveil Electric Roadway that Wirelessly Charges Electric Vehicles).

The solution uses steel belts embedded in rubber tires as collector and two electrodes buried beneath the road surface as power source. The researchers designed a 1/32 scale EV to proof their concept for the electric car. The car moved successfully with a power penetration efficiency exceeding 75% at 52 MHz (World's first demonstration of power transfer from wheels to power an electric car).

Specification

Parameter	**Value**
TRL Level	9
Voltage	Input: 12v Output: 40
Current	1.3A
Power rating and Power Range	13W
Overall System Efficiency	70%
Airgap	Few mm
Ground Module Dimensions	108x20x16mm
On-vehicle equipment Dimensions	76.5x11.5x11mm
On-vehicle equipment weight	32.5kg
Maximum operation temperature	0- 40 C

4.7 Dynamic System Summary

The table below summarises the principal parameters (where available) of the dynamic charging systems analysed. Static systems and research projects are not included in this summary.

Table 11: Summary of Dynamic Power Transfer systems' parameters

Parameter	Polito CWD	Vedecom/ Qualcomm	SAET IPV	Scania Primove	UNPLUGGED 3.7 kW	UNPLUGGED 50 kW	KAIST	Volvo Alstom ERS	Siemens eHighway
Type	Wireless	Wireless	Wireless	Wireless	Wireless	Wireless	Wireless	Conductive	Conductive
Operational speed	50 km/h		80km/h	90km/h	0	0	variable	90 km/h	90 km/h
Voltage	Output: 600 VDC	Output: 300-400 VDC	Input: 400AC 3phase LV	Output: 750 VDC	Primary: 400 VAC, 3 phase Secondary 700 VDC,	Primary: 230 V AC, one phase Secondary 250 V DC,	3 phase 380V or 440V AC	690V (750V from substation)	750 VDC
Current	34 A	Up to 67 A			up to 100 A	Primary 16 A Secondary 10 A	200A (20kHz)	175A	
Power rating	20kW	Up to 20 kW	100kW	200kW	50 kW (2 * 25 kW)	3.7 kW	Up to 200 KW	120kW	
Overall System Efficiency	>75%	Target 80%	70-80%	80% - 90%	90%	84%	75% (Dynamic)	97%	90-97%
Operating	20-200 kHz	85 kHz	60-	20 Khz	20-30 kHz	145 kHz	20 kHz	N/A	N/A

Frequency			150 kHz				(60 kHz successfully tested)		
Air gap	200mm	125-175 mm	250mm		180 to 250 mm	up to 170 mm	270mm	500mm	5m overhead
Ground Module Dimensions	0.5x9x0.024 Coil: 0.5x1.5x0.02m					700 x 500 mm	2.5m to 24m	.0,5x1,5x0,5 m	N/A
On-vehicle equipment Dimensions	0.7x0.3m		Secondary 1.8m x 1m	2m x 1m		290 x 330 mm	80*170*8 cm	Pickup (+80kg)	N/A Pantograph
On-vehicle equipment weight				Pickup + platform 330kg Control 60kg		3.7 kW System: app. 15 kg	80kg	Power converter (+40kg)	

4.8 Discussion

In this analysis, we have considered the current state of power transfer systems. These have been considered in the following categories:

1. Wireless dynamic power transfer. These are of the most interest to the FABRIC project as the trials envisaged are expected to make use of wireless power transfer.
2. Wireless static power transfer. Essentially these are very similar to dynamic systems, but are significantly easier to implement as rapid switching of the power systems is not required.
3. Conductive power transfer. These systems require a physical connection between the charger and the vehicle being charged.

The analysis has concentrated on systems which are close to market, i.e. they have been trialled or are being used in pilot projects. In addition, we have identified and briefly described systems which are still in the research phase.

4.8.1 Wireless Dynamic Power Transfer

All wireless dynamic systems use a form of resonant inductive coupling. This operates on the same principal as a transformer, but at a much higher frequency (tens or hundreds of kilohertz rather than the 50 Hz), and with both the primary and secondary coils forming part of a resonant circuit. These two differences are both crucial to achieving efficient power transfer over an air gap of tens of centimetres required for vehicles using public roads.

As shown in Table 11, most of the dynamic wireless power systems, all of which use resonant inductive coupling, have a maximum operating speed of 90km/h or less. It is clear that as a potential power source for all classes of electrically powered vehicles, this would, if it were a fundamental limitation of inductive power transfer, be a significant stumbling block to the widespread adoption of dynamic wireless power transfer. Discussions with various suppliers and researchers have made it clear that there is no fundamental speed limitation for inductive power transfer system. The principal reason for the upper speed quoted is that these are the speeds to which the systems have been designed and tested. This is driven by a perception that early adopters are likely to be long haul large trucks, which tend to be limited to 90 or 100 km/h.

The upper practical limit for speed of operation is set more by the size of the coils utilised in the power transfer system as high speed systems would require very rapid switching on and off of coils to maximise the time available for power transfer while the vehicle is over the coil in

question. Some systems are already addressing these limitations by energising coils as the vehicle approaches, ensuring that the primary coil is fully energised by the time the secondary coil is in a position to receive power. Long coil lengths are also used by some systems to increase the time available for power transfer.

A further indication that speed of operation is not a limiting factor is that systems using resonant inductive coupling are being developed for high-speed rail where speeds can exceed 300 km/h.

To ensure that a vibrant market exists for wireless power transfer, multiple manufacturers should be able to provide competing systems. However to gain widespread acceptance, It is generally accepted that systems will need to be interoperable. While the core technology is similar for all the systems considered, the frequencies at which they operate is not standardised, which means that the systems are incapable of interoperating. It is currently difficult to achieve consistency in the frequency of operation. Low power systems tend to operate at higher frequencies as efficiency tend to improve with increasing frequency; however the technology currently available means that higher power systems need to work at lower frequencies as the power electronics for high power high frequency operation are not yet available.

Furthermore, the coil sizes and circuit topologies will need to be standardised to maintain efficiency between interoperating systems. Currently each manufacturer optimises the size of their primary and secondary coils for their system.

For some circuit topologies, it is also important the primary and secondary powers are matched. This is because for those topologies which create a constant current secondary (see the description in the Appendix on Wireless Power Transfer), the power transferred to the secondary is controlled from the primary, and supplying too much power will damage or destroy the secondary charging circuits.

4.8.2 Wireless Static Power Transfer

These systems currently also all use resonant inductive coupling. It is for this reason that most dynamic systems have been developed from static systems.

While static systems are further developed, and indeed systems are already available to purchase, they suffer from some of the same issues as dynamic systems. The current market for static systems is such that interoperability is not as much of an issue as dynamic systems, as these systems are largely sold to individuals and companies where the primary and secondary are supplied by the same supplier. However, a natural expansion of the static market

is into the so called stationary market, where charging systems are installed in public places (car parks, taxi ranks etc.) where interoperability will become far more important.

The UNPLUGGED project is addressing these issues by developing 3.7 kW and 50 kW systems which will interoperate. However interoperability between commercial systems will require significant standardisation efforts.

4.8.3 Conductive Power Transfer

A small number of conductive power transfer systems have been identified. Note that plug-in conductive systems have not been considered.

Three dynamic conductive systems have been considered. Two use in-road live rails, and one uses an overhead, twin power cable system. While these systems are essentially similar to existing rail, light rail and metro rail systems, they have one crucial complicating factor in that two conductors are require, a live conductor and a return conductor. This is because rail systems can use the rails as the return conductor, an option not available to rubber tyred vehicles.

In-road systems need careful control as the supply rails cannot be left live for safety reasons. This means that the charging systems needs to detect the presence of a connected vehicle, and only switch on the supply to that section of the supply rail to which the vehicle is connected at the time. In addition, road mounted systems need to be able to cope with foreign objects on the rails. The two systems identified are proprietary and not in any way interoperable. The maximum speed indicated for the Volvo-Alstom system of 90 km/h is not fundamental to this type of power transfer, as witnessed by various “third rail” rail systems which use this type of power system, but is the upper limit of current testing. It is possible that operating at higher speeds will require enhanced mechanical design, and hence may increase costs. This has not been investigated.

One overhead conductive power transfer system has been identified. This uses twin overhead conductors like a trolley bus, but the pick-up is via side by side sliding pantographs similar to those used in rail systems. The pantograph requires careful side to side control to ensure that the pick-ups connect to the correct conductor. The parameters identified in Table 11 indicate a maximum speed of 90 km/h for the overhead conductive system considered. This is not fundamental to this type of system, as indicated by the fact that high-speed rail systems use similar arrangements at speeds exceeding 300 km/h.

While overhead systems are inherently safer than in-road systems so do not require high-speed power switching, they are visually intrusive and will struggle to cope with vehicles of significantly different heights, for example passenger cars and HGVs.

There is currently no standardisation effort being conducted in the area of on-road conductive power transfer.

4.8.4 FABRIC power transfer solutions

The FABRIC project has been tasked with researching dynamic power transfer solutions, including carrying out test track trials to assess both the technology and future feasibility of dynamic systems. To this end, a selection of available solutions was selected for research and trialling.

The Polito CWD WPT system and the Saet IPV system are both inductive systems. One of the key attributes of these systems is that they will be used to investigate interoperability between two systems of different circuit topologies. Polito will supply a complete system with a constant voltage secondary output. The Saet system, when inductively coupled to the Polito secondary, will result in a constant current secondary. In the FABRIC test environment, the Polito secondary will detect the Saet primary in real time and switch to constant current secondary operation, thereby proving that real time interoperability between systems with different circuit topologies is possible.

The Vedecom system will use technology from Qualcomm in a trial at the Satory test site in France. The Qualcomm Halo system is based on research done in Auckland and has been extensively developed. The dynamic system being proposed has been developed from and existing static and stationary product. This product has been selected to show how existing systems can be adapted for use in the dynamic environment.

The Scania-Bombardier Primove system is also an inductive power transfer solution. This system is included as part of the research, but will not be trialled in FABRIC. The system has previously been trialled and results from these trials will be analysed in FABRIC.

Finally the Volvo-Alstom Slide-in Electric Road System is included as a conductive dynamic power transfer system. Again this system will not be trialled in FABRIC, but results from other trials will be analysed and reported on to draw comparisons to the wireless systems being trialled.

5 MARKET READINESS

5.1 Introduction

In the recent years there has been a significant turn towards the research and development of vehicles with electrical propulsion. There were incentives from governments in an effort to decarbonize transportation which is a major atmospheric pollutant via greenhouse gases that conventional gasoline and petrol-fuelled vehicles produce when they operate. In parallel, several vehicle manufacturers have introduced hybrid and fully electric vehicles to the market trying to achieve the critical mass of buyers that will allow the large scale penetration of electromobility in the transportation sector.

The efforts above can be categorized in several ways: Research and development backed by governments and the EU through co-funded R&D projects, R&D done by the industry and vehicle manufacturers, R&D that is aimed at the actual electric vehicles, R&D targeting the electric vehicle charging infrastructure and also the grid and finally there can be a categorization depending on the different charging modes e.g. static, stationary or dynamic charging.

Further categorization is possible based on the technologies used for each charging mode.

This document initially presents an overview of the state of electromobility around the world and of the major R&D projects promoting it. It also provides a list of electromobility developments stemming from the industry and vehicle manufacturers. In the second part of the document there is a methodology for obtaining market readiness data and quantifying the results using technological and manufacturing indexes. This methodology was used to make a measurable market readiness assessment of current solutions by vehicle manufacturers but also near future projections.

5.2 State and Trends in Electromobility

Electromobility is basically the propulsion of vehicles using electricity as "fuel". It aims at large-scale adoption of electric vehicles by the population in order to reduce greenhouse air pollutants and provide the means for even wider implementation of smart grids. Electromobility requires advances in electric powertrain technologies, V2V and V2I information and communication technologies (ICT) and smart-grid integration technologies. These advances are expected to make transportation environmentally friendlier and also safer.

In addition, the use of renewable energy sources to directly charge the electric vehicles allows power generation in the vicinity of demand thus reducing losses and the need for expensive investments to transfer the energy to distant locations.

The new functionality of the vehicle as a large energy storage unit presents both the owner and the stakeholders of the energy market with significant potential advantages that conventional mobility could not offer:

- The vehicle owners may use the vehicle's battery as an energy source that can power their house. They also may connect the EV to the smart grid and sell the energy to the energy provider thus becoming "prosumers" (consumers and producers). The monetary gain potential may facilitate the adoption of electromobility by the general public.
- The vehicle becomes a means to transport energy to distant locations. In that way it becomes a decentralized power source.
- The dual function of the electric vehicle, which can operate both as an electric load and a power storage/generation unit shows significant potential as a means to lower operational costs in the energy market. Via the smart grid infrastructure, energy stored in EVs can be bought back when there is a demand peak, and the EVs can recharge at a lower cost when there is a lot of supply.
- EVs may offer the solution for storing energy produced by renewable energy sources, thus allowing their greater penetration and utilization. A direct result is the reduction of the overall energy production cost and cleaner environment.
- Cleaner city air and quieter vehicles are the immediate benefits for the citizens while the industrial and employment boost accompanied by reduction of climate change catastrophic phenomena that cost billions each year will greatly benefit the countries that manufacture vehicles and components or provide electromobility related ICT services.

Note that the above potential advantages are necessarily speculative and, while technically feasible, are not proved to be practically achievable.

There are several types of EV charging considered in this section:

- **Static charging:** typically the vehicle is parked (garage, parking lot, bus terminal…), for a long duration of time. During the time that the vehicle is parked to the charging infrastructure it charges based on several parameters that are specific to the battery of the EV and the capacity of the charging infrastructure. This is the most usual type of charging and there are several thousand installations around the world currently in operation. The charging duration typically lasts for several hours, however recent advances have reduced the charging time to 30 minutes.
- **Stationary charging:** The vehicle is en-route and stops for a short period of time (car waiting at the traffic light, bus at a stop, etc.). Typically the driver (and passengers) are on board. The charging lasts between seconds to minutes and high power is transferred

from the infrastructure to the EV. There are several stationary charging systems installed around the world and functioning for years without problems. The advantage is that the batteries are much smaller in size and the charging lasts less.

- **Dynamic charging:** The vehicle may travel at constant or variable speed typically in a devoted special lane that hosts the charging infrastructure. The EV is being recharged while travelling without the need to stop for recharging. Currently there aren't many solutions available for dynamic charging. The advantage is reduced battery size, increased EV range and of course increased comfort.

Note that the terms static and stationary charging are not standardised, and some publications interchange these definitions.

5.2.1 State of electromobility around the world

The 'Electromobility Index' compiled by Roland Berger and the Aachen-based Forschungsgesellschaft Kraftfahrwesen (Research society for Automotive Issues) compares the competitive position of seven leading automotive economies - China, France, Germany, Italy, Japan, Korea and the U.S. - regarding electromobility.

According to the report Japan is the leader in electromobility penetration to the transportation market. This is due primarily to the lower cost of EVs in Japan compared to the other countries. In addition the charging infrastructure is more mature in Japan whereas in Europe the lack of such an infrastructure, interoperability and standardization issues present roadblocks towards the large-scale adoption of electromobility. Battery manufacturers in Japan (and in South Korea) master the entire battery production value chain, resulting in a competitive advantage for these countries. A similar approach is followed in the US with Tesla motors announcing the creation of a "gigafactory" for lithium-ion batteries which is expected to lower production costs, hence EV cost for the US consumer, leading to wider adoption.

Currently the US remain the lead market with 96.000 EVs sold in 2013. However, this is just a relatively small share of the total market. Under this aspect, France holds the top position: The share of e-cars in the total French market is 0.83%, US (0.62%) and Japan (0.59 %). In Germany, electric vehicles have a very small market share of 0.25% or just 7400 units sold.

Even though electromobility penetration levels worldwide are not impressive, the trend is upward and more car makers introduce electric models to the market. Research during the recent years focuses on reducing the recharging time for static charging (wired and wireless) and in parallel explores the transition from static charging to stationary and dynamic or on-the-go charging which allows for smaller batteries and faster recharging, alleviating many of the

current EV charging issues. At the same time investments in EV charging infrastructure continue to grow as it can be seen here.

Electromobility R&D initiatives underway around the world:

Europe

The European Parliament just passed a resolution in 2013 that will require member states to install a specified number of electric vehicle charging stations and hydrogen and natural gas stations by 2020. Germany will set its target to 86,000, Italy will install 72,000, and the UK is planning to build a minimum of 70,000 EV recharging points. http://bit.ly/1u3deei

In parallel, several national projects run to promote the larger adoption of electromobility:

- Electric vehicle start-up, Fastned, will install over 200 fast charging stations with solar panels in Netherlands http://www.fastned.nl/en
- Nationwide network of quick chargers in Estonia http://elmo.ee/charging-network/
- CLEVER opened in June 2012 the first public accessible nationwide charging-network for EVs in Scandinavia. https://www.clever.dk/english/

North America

With companies such as Delphi and Qualcomm, working with the main US vehicle manufacturers to develop the building blocks of the wireless charging infrastructure. (The US Transportation Electrification Program represents the world's largest EV demonstration project).

Asia

Asia is expected to lead the world in charging equipment sales due to government initiatives and regulations in China, Korea, and Japan to promote awareness and adoption of EVs comprising of tax benefits for owners, R&D support, and public education programs.

Toyota, Nissan, Honda and Mitsubishi have agreed to joint development of charging infrastructure for PHVs, PHEVs and EVs in Japan aiming to increase the number of normal chargers by 8000 and quick chargers by 4000 http://www.nissan-global.com/EN/NEWS/2013/_STORY/130729-01-e.html

5.2.2 State of Development of Charging Infrastructure

Below is an indicative but not exhaustive list of EV static, stationary and dynamic wireless charging systems (inductive and conductive) that are currently in various research, development and deployment stages:

Fast static plugin

- Tesla motors network of superchargers, allowing half charging within 20-minutes, see http://www.teslamotors.com/supercharger

Conclusion:

The plugged-in charging technology has been available for many years allowing the slow recharging of hybrid and full electric vehicles which lasts up to 8 or more hours for a full recharge. The infrastructure is continuously growing due to governmental or private initiatives. Efforts are now put towards the reduction of the charging time via the development and deployment of fast chargers. The technology is already marketable and commercially available.

Static wireless

- Large scale pre-commercial trials of the QUALCOMM HALO WEVC in London http://www.qualcommhalo.com/index.php/wevc-trials.html
- Large scale trials of EVATRAN Plugless™ L2 wireless charging system 15 installations across the US http://www.pluglesspower.com
- Hertz car rental company utilized the EVATRAN wireless charging network in the US http://cleantechnica.com/2012/02/10/hertz-tests-wireless-ev-charging-in-the-u-s/.
- HEVO Power's wireless charging station in the form of a manhole cover that will be tested in New York City. http://www.hevopower.com
- Several automakers, including BMW, Daimler, Volvo Car Corp., Nissan Motor Corp. and Volkswagen Group have announced the development of vehicles with wireless charging capacity. Toyota has licensed wireless charging technology from WiTricity.

Conclusion:

Static wireless charging is a technologically mature solution which has been tested extensively and the related products are ready to reach the market. Major vehicle manufacturers and OEMs are expected to provide wireless charging stations and EVs within the next one or two years.

Stationary wireless

- Manhole cover charging in NYC: HEVO Power, which is conducting a manhole pilot with New York University http://www.eenews.net/stories/1059989839
- Brabant NL to deploy world’s first dynamic mobile charging: Starting in mid-2013 the demonstration project will use inductive charging to charge vehicles as they drive a special lane in the highway. http://www.youtube.com/watch?v=IBTx87xiscs, http://www.wired.com/autopia/2012/10/glowing-roads/

- Shanghai Capabus: China is experimenting with a type of electric bus, known as Capabus, which runs by using power stored in large on-board electric double-layer capacitors (EDLCs) that are recharged whenever the vehicle stops at a bus-stop http://www.sinautecus.com/products.html
- Bombardier Primove high power inductive charging station to be used for stationary charging of buses in Germany http://primove.bombardier.com
- Conductix-Wampfler electric buses charge wirelessly during brief stops. Tested for several years in Genoa and Turin http://www.conductix.com/en/news/2012-05-31/10-years-electric-buses-iptr-charge
- Utah State University spin-off WAVE lunches electric buses with stationary wireless capability. Tests in several US cities. http://www.waveipt.com/blog/new-wave-electric-buses-developed-usu

Conclusion:

Stationary wireless charging is a technologically mature solution which has been extensively tested for buses. The EVs and infrastructure products are already marketable and their commercial exploitation has begun.

Wireless dynamic charging

- New Zealand HaloIPT Induction Dynamic Charging http://www.haloipt.com/. The HaloIPT system was bought by QUALCOMM and market-ready solutions for stationary inductive charging are currently in operation. In FABRIC, research is being carried out to utilize the system for dynamic charging.
- Korean On Line Electric Vehicle (OLEV), dynamic charging implementations of the system are already in use at South Korea http://olev.kaist.ac.kr/en/
- E-quickie research vehicle that uses dynamic charging developed in Karlsruhe University of Applied Sciences (HsKA). http://www.gizmag.com/e-quickie-electric-vehicle-with-wireless-energy-transmission/16346/

Conclusion:

With the exception of KAIST OLEV, the dynamic charging technology is still in R&D phase.

Conductive dynamic charging

- Volvo GTT and Alstom work on the development of “Electric Road Systems”. Slide-in Electric Road Systems can be described as electrified roads that support dynamic power transfer to the vehicles from the roads they are driving on. The basic principle is to

power an electric engine within the vehicle from an external power source that is built into the infrastructure of the road. The electric power is transmitted while the vehicle is in motion, through a “pick-up” (current collector) mounted on the vehicle. http://bit.ly/1u3fkuR

- Siemens eHighway dynamic charging for trucks http://sie.ag/1n0BB8r . Siemens has just announced a project in Southern California, which will realize the first demonstration of eHighway on a public road. This marks a major milestone for proving the maturity of the concept and enabling real-life evaluation of economic and environmental benefits, as well as ensuring the system and road regulations are compatible with each other. The purpose is to facilitate evaluation of larger systems in commercial operation, primarily for shuttle applications where a road is intensely used by heavy duty vehicles. http://sie.ag/1ldQF5v
- Elways is expected to test its electric road solution in public road within two years http://bit.ly/1qglvtk

Conclusion:

Conductive dynamic charging is out of the laboratory environment and is being tested on regular roads. However commercialization is expected to take more time due to the significant investments required to transform normal roads to electric roads.

5.2.3 Trends in electromobility

Static plugin charging is a mature technology and the norm in EV charging. There are already a very large number of static electric plug-in chargers installed around the world, as shown in Figure 49 and this number is increasing continuously due to government initiatives that promote the change to electromobility.

Plug-in systems have some inherent issues that hinder the wide adoption of EVs. A major obstacle is the time needed to recharge the batteries. Typically, recharging lasts for several hours when using low voltage and amperage power outlets, which limits the usage of EVs. The typical scenario of use for these vehicles entails usage during the day and charging during the night. Even though this scenario is feasible it causes a feeling of limitation to the EV owners which when paired with the limited range of current EVs, prevents the large penetration of EVs in the transportation market. Furthermore dedicated charging facilities are required at the user’s home such as garages with dedicated power line, however this infrastructure is not easy to be found in apartment building dominated cities. Another scenario is charging during the day when the EV owner is working but this scenario also suggests the availability of infrastructure in large

parking lots, while there is the additional problem of adding another load to the grid during demand peak hours. Advances in static charging technology have reduced the time needed to 20 minutes for a half charge using fast chargers, however when travelling, this time is still long when compared to the refuelling time of conventional ICE vehicles that also have greater range.

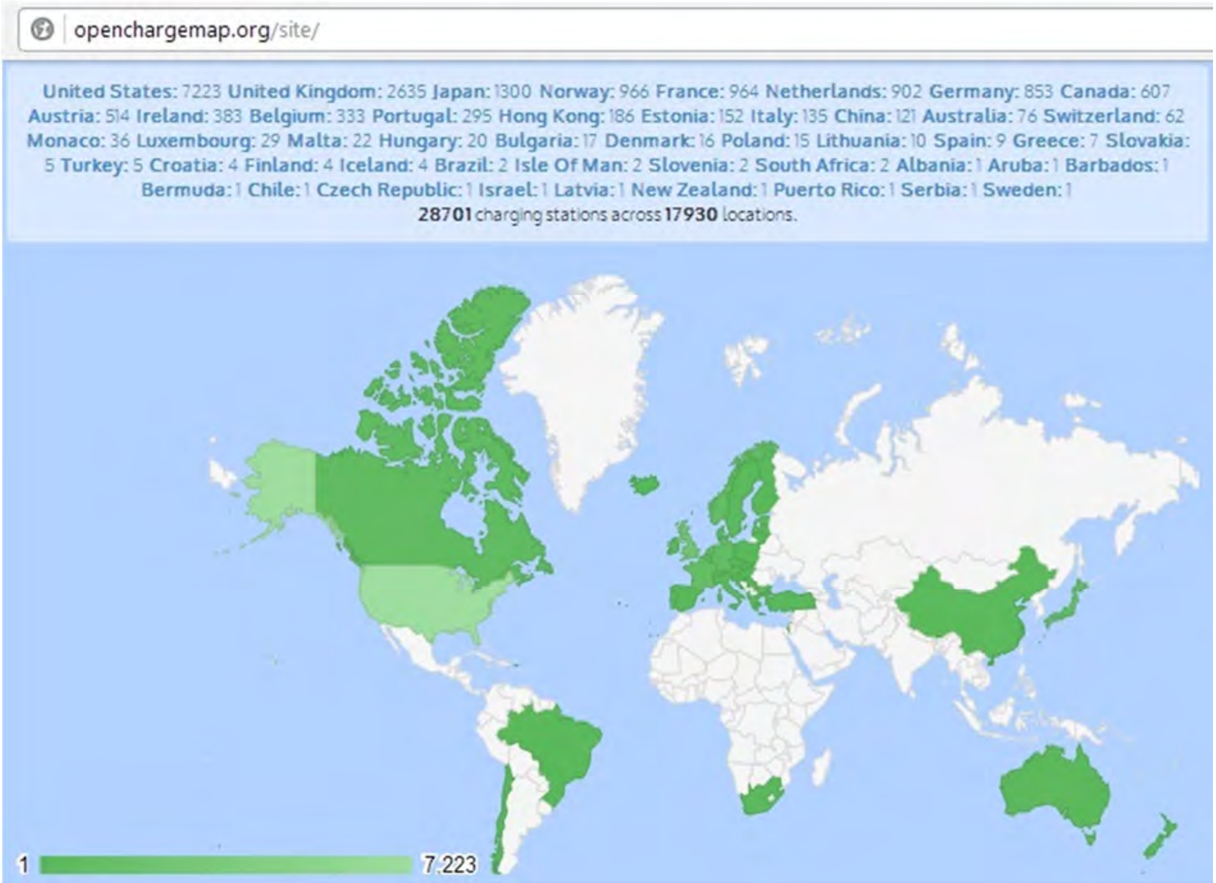

Figure 49: Distribution of charging stations installed around the world

A second factor for the low EV penetration is the cost of the batteries which is relevant to the battery size. In order to increase EV range the manufacturers are pushed to use larger batteries, which affects the car’s weight and price.

Finally users do not like the hassle associated with plugging in the EV for recharging.

Dynamic charging aims at alleviating some of these issues thus easing the path towards large-scale adoption of electromobility. The advantages of dynamic charging comparing to static are:

- Smaller batteries, since the EV will be able to pick up energy from the road while travelling. This should also affect the price of the EV.
- Hassle free charging. In theory recharging the vehicle could be as unobtrusive as driving normally on a highway lane. No need to plug in cables thus also avoiding safety risks

associated with worn-out infrastructure cables, vandalism, weather conditions (e.g. handling cables in the rain) etc.

- Charging on the go means that the EV will not have to stop to recharge which is an advance even compared to conventional ICE vehicles. The comfort factor is expected to be a major decision factor for buying an EV in the future.

The advantages and disadvantages of various charging technologies for EVs are shown in Table 12.

Table 12: Advantages and disadvantages of various EV charging technologies

Plug-in		Conductive		Inductive	
Cons	Pros	Cons	Pros	Cons	Pros
User discomfort	Mature technology	Visual pollution	Easy installation	Expensive infrastructure	Smaller batteries
Long charging duration		Expensive pantograph systems	Smaller batteries		Cheaper EVs
Large and expensive batteries			Extended range		Extended range
Expensive EVs			Comfort		Comfort
Vehicle must be parked			Increased mobility		Increased mobility
					No visual pollution

The advantages above do not consider however the cost for building such a solution. In order to provide the ability to recharge dynamically great investments need to be made in transforming parts of the roads into energy transfer conductors. The advantages above do not consider however the cost for building such a solution. In order to provide the ability to recharge dynamically great investments need to be made in transforming parts of the roads into energy transfer conductors.

5.3 Market Readiness Survey

5.3.1 Methodology

The state of the art study identified the major companies and institutes that are active in the research and development of EV charging systems (dynamic, stationary, static, wireless and

conductive). A list of contact persons in these organizations was compiled and a survey took place in an effort to determine first hand with information coming from within these organizations the market readiness of whole EV charging solutions but also critical subsystems which would allow the detection of bottlenecks towards the commercialization of the various charging systems. Since there is no clearly defined metrics for market readiness it was decided to estimate it indirectly by using the Technology and Manufacturing Readiness Levels that can be assessed using a 1-10 scale that provides standardized descriptions for each level.

The standards for assessing Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs) are based on Low Carbon Vehicle Partnership's (LowCVP) previous work[2]. These are explained in the following sections.

5.3.2 Technology Readiness Level (TRL)

The concept of Technology Readiness Levels (TRL's) has been developed as a tool to assist in monitoring technology development and is now very familiar in the innovation lexicon. The term originated with NASA in the 1980's in order to help management make decisions concerning the development and transitioning of technology (Sadin, Povinelli, & Rosen, 1989). The basic scale has been modified over time through use in the space, energy and transport industry as well as the military, with most systems now recognizing nine levels, and extending its value to other spheres enabling organizations to demonstrate their role in the process of technology development e.g. the UK Technology Strategy Board (http://bit.ly/o3vUUy).

Current Technology Readiness Levels (TRLs) convey the development status of a technology to deliver its function. These range from desk based research to demonstration and validation to a product proven for mass market adoption. In Table 13 below the ten TRL levels are defined.

[2] Automotive Technology and Manufacturing Readiness Levels, A Guide to Recognised Stages of Development within the Automotive Industry, Automotive Council, January 2011 development status of technologies as they move from a researched concept to a validated product that has been designed for scale manufacturing.

Table 13: Technology Readiness Levels

Technology Readiness Levels		
Research	TRL 1	Paper studies and scientific experiments have taken place; Performance has been predicted;
	TRL 2	Application specific simulations or experiments have been undertaken; Performance predictions have been refined;
	TRL 3	Performance investigation using analytical experimentation and/or simulations is underway;
Demonstration	TRL 4	The technology component and/or basic subsystem have been validated in a laboratory or test house environment;
	TRL 5	The component and/or basic subsystem have been validated in a relevant environment, e.g. via a mule or adapted current vehicle;
	TRL 6	A prototype of the system or subsystem has been demonstrated within a test house, test track or similar operational environment;
	TRL 7	Multiple prototypes have been demonstrated in an operational, on-vehicle environment;
Product readiness	TRL 8	The technology has been proven to work in its final form and under expected conditions;
	TRL 9	The technology has been successfully applied in its final form and under real-world conditions;
	TRL 10	The technology is successfully in service in multiple application forms, vehicle platforms and regions;

5.3.3 Manufacturing readiness level (MRL)

Manufacturing Readiness Levels (MRLs) communicate the maturity of a product to be produced. These range from proof of concept through prototyping to volume production, deployable globally and to appropriate quality levels. In the table below the ten MRL levels are defined.

Table 14: Manufacturing Readiness Levels

Manufacturing Readiness Levels		
Proof of concept	MRL 1	Basic manufacturing implications have been identified;
	MRL 2	Manufacturing concepts and feasibility have been determined and processes have been identified;
	MRL 3	Experimental hardware has been created, but is not yet integrated or representative; Supply chain requirements determined;
Prototypes	MRL 4	Capability exists to produce the technology in a laboratory or prototype environment; Design optimised for production;
	MRL 5	Capability to produce prototype components in a production relevant environment;
	MRL 6	Capability to produce integrated system or subsystem in a production relevant environment;
	MRL 7	Capability to produce systems, subsystems or components in a production representative environment; Procurement plans made;
Low & high volume production	MRL 8	Initial production is underway; An early supply chain is established and stable; Manufacturing processes have been validated;
	MRL 9	Full/volume rate production capability has been demonstrated; Major system design features are stable and proven;
	MRL 10	Full Rate Production is demonstrated; Lean production practices are in place and continuous process improvements are on-going; The manufacturing capability is globally deployable;

5.3.4 Market readiness questionnaire

In FABRIC the market readiness assessment is a function of the technology and manufacturing readiness levels for whole charging systems and for critical components, as perceived by participants in a marker readiness survey. This allowed the assessment of the system as a whole but also pinpointed areas that hinder the market deployment of otherwise mature products. Three major high-level component areas have been identified:

- The power transmission area,
- The power reception area
- The communications

Participants were also encouraged to provide more detailed information pinpointing specific crucial components that may hinder the TRL and MRL of the final system.

Participants were requested to fill-in two assessments:

- The first one refers to the system's current readiness levels
- The second one is a subjective estimation of the readiness levels in a year from now.

This allowed us to make a projection of the maturing rate of products in the area of EV charging towards market deployment. The full questionnaire is included in the Appendix.

Different technologies that target at different charging modes (static, stationary, dynamic) have different technological and investment requirements, which of course affect their technology, manufacturing and market readiness levels. With that in mind the survey replies were grouped according to the charging technology and mode in order to allow for the extraction of meaningful conclusions.

The survey focused mainly on wireless charging modes since static conductive charging can be considered a mature and market ready technology due to the fact that there are already a lot of static charging products available to the consumer. The interest in static charging mode was focused on wireless static charging which even though it has been widely tested, hasn't been mass produced and deployed in a large scale yet.

14 companies were contacted to participate in the survey as shown in the table below.

Table 15: Companies contacted for the Market Readiness Survey

Companies and institutes contacted to participate in market readiness survey	Solution	Charging mode
Conductix-Wampfler	IPT	Static wireless
EVATRAN	Plugless power	Static wireless
HELLA		Static wireless
QUALCOMM	HALO	Static wireless
WiTricity		Static wireless
Bombardier	Primove	Stationary wireless
Sinautec Automobile Technologies	Capabus	Stationary wireless
Utah State University	WAVE electric buses	Stationary wireless
Elways	Electric road	Dynamic conductive
Siemens	eHighway	Dynamic conductive
Alstom	Slide-in ERS	Dynamic conductive
INTIS	INTIC	Static/dynamic wireless
KAIST	OLEV	Dynamic wireless
Oak Ridge National Laboratory	ORNL dynamic charging	Dynamic wireless
VeDeCom	QUALCOMM HALO IPT adaptation	Dynamic wireless

About two-thirds of the companies responded.

5.3.5 Market readiness survey conclusions

Detailed responses were provided in confidence, so only a summary of results will be presented.

Due to the low number of participants in the survey we cannot draw definitive conclusions for the market readiness of various charging solutions currently under development or testing so the main conclusions will derive from the state of the art review. The results of the survey are

depicted in the following figures. The market readiness can be indirectly estimated as a function of the technology and manufacturing levels for the systems as a whole and critical subsystems e.g. power transmission and reception and communications.

Figure 50 shows the MRL and TRL of various charging technologies at the time of the survey and one year hence.

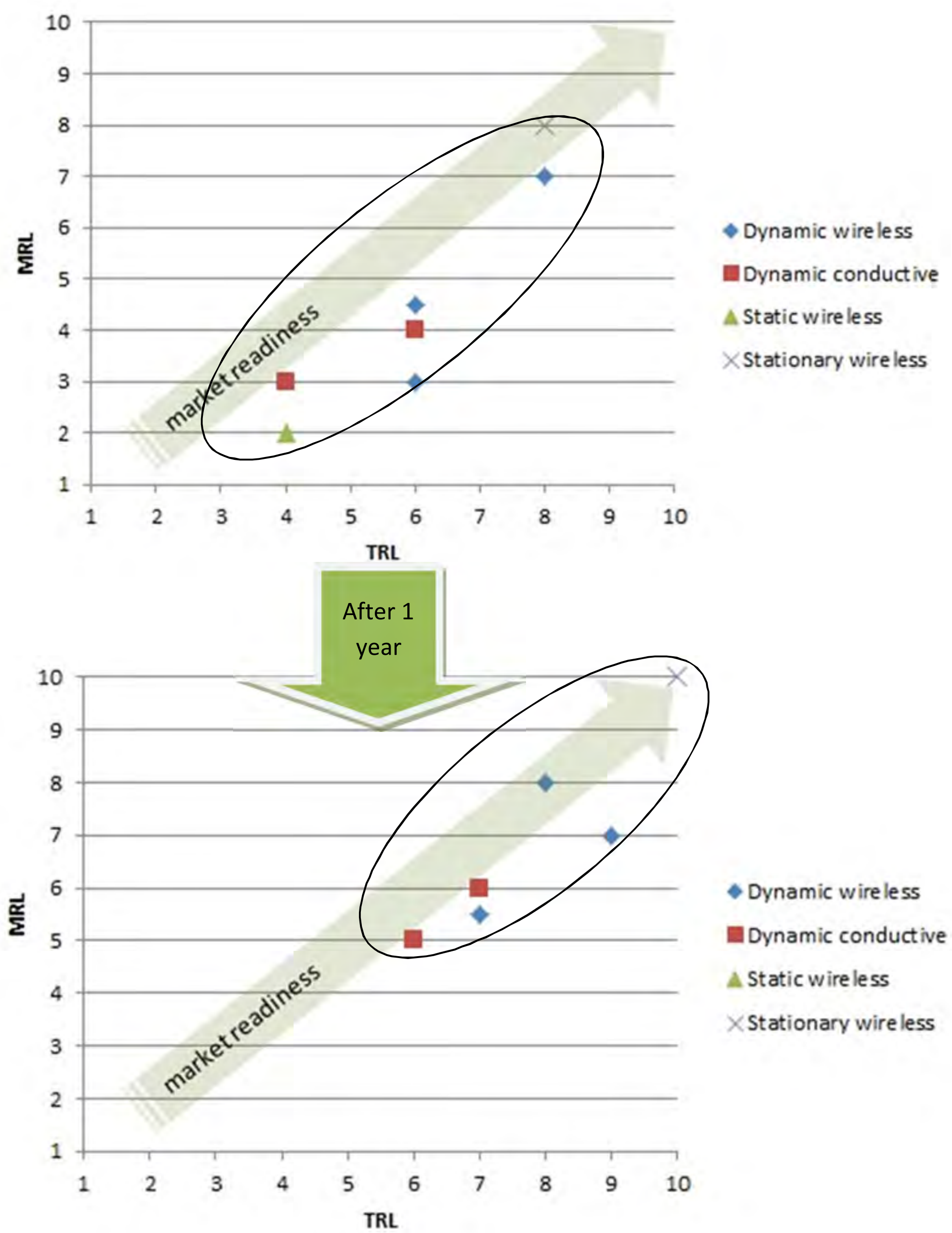

Figure 50: MRL and TRL of charging systems

A conclusion we can reach from the above concerns the progress trend towards market readiness of dynamic conductive and wireless charging solutions that are currently in R&D

phase. There are optimistic estimations about the near-future market readiness state of dynamic charging products. However the actual deployment and commercialization of these products depends heavily on the infrastructure investments that governments or the private sector are willing to make.

Figure 51 summarize the results for the main components of an EV charging system.

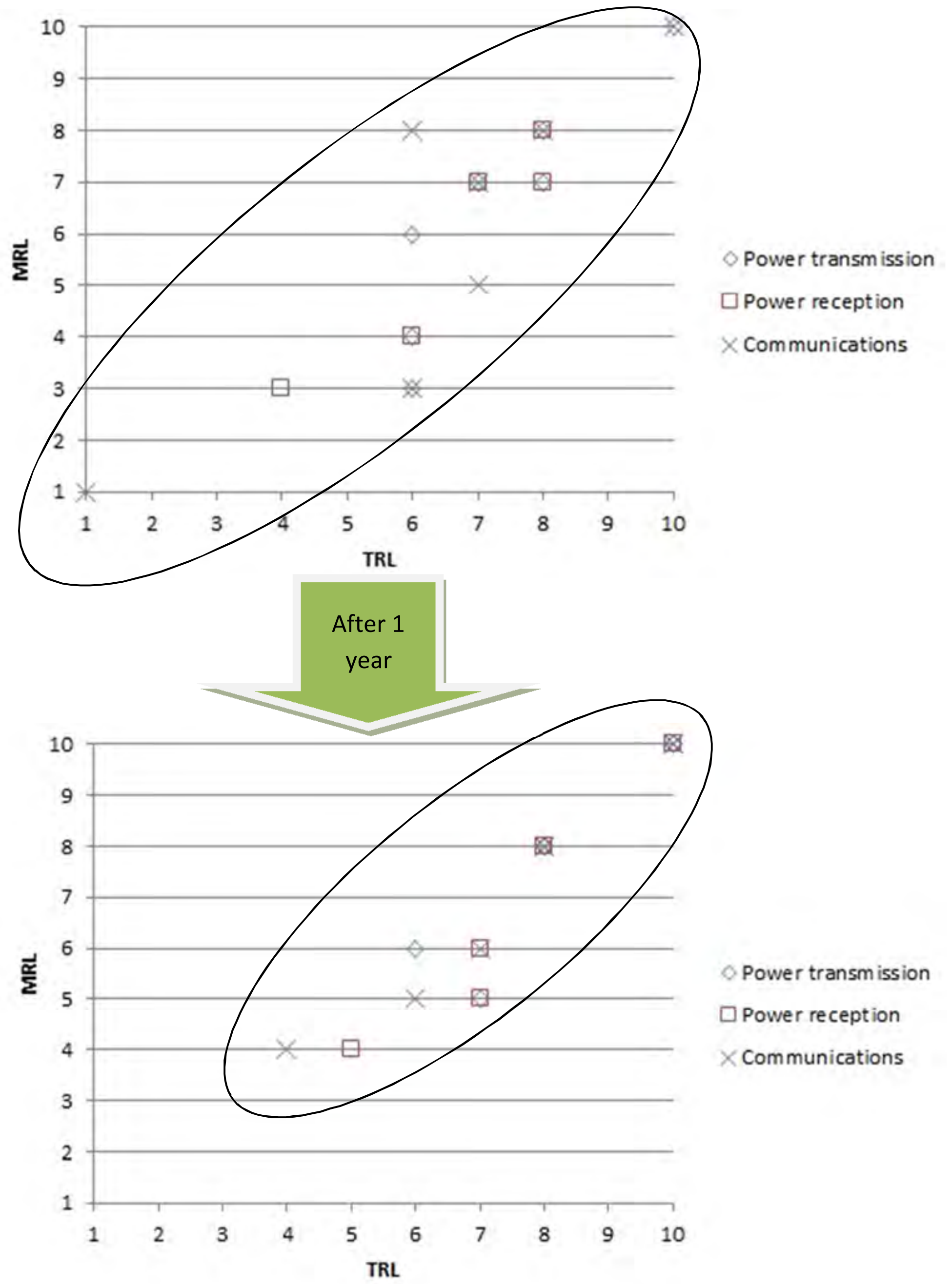

Figure 51: TRL and MRL for the main components of an EV charging system

Again, regardless of the absolute values that vary significantly among the various survey participants, the most important conclusion that can be drawn is the significant improvement

that is expected over the next year in both the MRL and TRL of the core components of wireless charging systems..

5.4 Conclusions

The major companies and institutes that are active in electromobility were contacted to participate to the survey. However the limited number of participants does not allow the extraction of reliable conclusions, therefore the outcome of the survey can be considered only as complementary to the main conclusions drawn by the state of the art review which are the following:

Static wireless charging is a technologically mature solution which has been tested extensively and the related products are ready to reach the market. Major vehicle manufacturers and OEMs are expected to provide wireless charging stations and EVs within the next one or two years.

Stationary wireless charging is a technologically mature solution which has been extensively tested for buses. The EVs and infrastructure products are already marketable and their commercial exploitation has begun.

With the exception of one supplier, the dynamic charging technology is still in R&D phase.

Conductive dynamic charging has been out of the lab environment and is being tested on regular roads. However commercialization is expected to take more time due to the significant investments required to transform normal roads to electric roads.

Regarding critical subsystems, from the limited dataset provided by the survey one can conclude that power transmission components (infrastructure side) are slightly more mature than power reception components (vehicle side) which is expected to a degree due to the increased complexity of the vehicle side systems. Regarding communications, the picture is not clear since most manufacturers focus on the power transmission side rather than communications which depend on the actual implementation architecture of their systems.

6 CONCLUSIONS

6.1 Power transfer solution

This deliverable is a review of the state of the art of power transfer solutions and communication methods. The main review was carried out on on-road power transfer systems; however the study also considered other potential solutions that could be re-engineered to operate in on-road mode.

The review of dynamic power transfer systems shows that all the dynamic systems are research projects. The KAIST solutions in Korea, which are in operation in various locations including on a commercial bus route, are closest to commercially ready dynamic charging solution, but even these solutions also benefit from static charging in the bus stops. There are static systems such as Conductix Wampfler and WiTricity which are fully operational systems, but at this stage there is no high level take-up of static or dynamic systems.

No extensive cost analysis had been carried out to calculate the cost of dynamic power transfer per km. As these projects are all still at a research stage, the cost of equipment, construction, maintenance may not be accurate; however, researchers predict total cost to be between €800,000,000 to €1,600,000 per installed km for fully developed system in a mature market.

The dynamic systems reviewed all operate on three phase 400V LV from the distribution supply; this is due to ease of access to the distribution power supply for research projects. The power transfer voltage to the vehicle is approximately 750V DC for majority of the reviewed systems; however the reviewed systems mainly concentrated on heavy vehicles, so implications of high voltage power transfer on smaller vehicles and their relatively smaller battery modules should be investigated. The supply from a low voltage local distribution connection to the charging system may not be possible for a fully operational system as the power and energy demand will be very high, but there is no fully developed strategy for grid connection. A direct supply from the grid, similar to electrified railways could be an alternative for a fully functional dynamic power transfer system.

The power transfer range varies for each system. For example the power transfer can be as high as 200KW, but high power rate such as this requires large and heavy secondary coils which may not be mechanically suitable for cars. The power transfer rate for secondary coils can range between 15KW-50KW per coil, and an array of these coils provides higher power transfer rates.

Static wireless power systems can have efficiencies high as 95%, but the dynamic systems tend to have lower efficiency rate, for example KAIST system achieves efficiency of 75-80% under

dynamic conditions and this value is similar in other dynamic systems. In comparison, the Volvo system has 97% efficiency due to its conductive power transfer nature.

The operation frequency of the power transfer varies depending on the system, however dynamic systems power transfer frequencies are below 30 kHz. The frequency for static system can be high as 145 kHz. The frequency values show the transfer frequency is lower for dynamic systems when compared with the static.

The air gap in dynamic systems is between 180-270 mm. the lateral misalignment allowed in dynamic systems range between 130mm-500mm depending on the solution.

The primary power transfer coils for wireless systems are usually loops of wire. The length of each wire can range between 1.5 metres – 24 metres (for the KAIST system), however there are also systems which use a series of small coils to transfer the power.

The size and the weight of the on board equipment is dependent on the power transfer parameters. For example 100KW systems the coil dimensions are approximately 1.8x1 metre weight in total 330kg. 30KW coil could weigh up to 70kg and power electronics are approximately 20-30kg.

The study shows that there is very little consideration on installation and integration of the systems into the road and the grid, this is due to solutions providers aiming to develop a technically operational system in early stages of the project before considering integration and installation methods.

6.2 Communications

FABRIC applications will be based on both short-range (local-area) and long-range (wide-area) wired and wireless communication technologies. The most prominent representative of short-range wireless communications are vehicular ad-hoc networks, like ETSI ITS-G5 based on IEEE 802.11p. These technologies may be used also for short-range V2I communication. For long-range communications, cellular networks such as 2G, 3G and LTE are potential candidates.

Current widely spread cellular infrastructure (GSM, UMTS) can cover applications and services that don't require high data rates and low latencies. Enhancements to these cellular network technologies have been reflected in the development of GPRS, EDGE, HSPA. The next generation of cellular networks that is introduced by technologies like WiMAX, LTE and LTE-Advanced, meet the requirements for increasing data rates and decreasing latencies in order to enable real time applications with high throughput demands.

Two types of nodes are most popular in vehicular networks: vehicles and roadside stations. Communications-wise they can be developed and implemented as Dedicated Short Range Communications (DSRC). DSRC uses the 5.9GHz band with a bandwidth of 75 MHz and an approximate range of 1km. In addition to DSRC, wired communications are also used in order to interconnect Road Side Units with ITS application enabling infrastructure.

IEEE 802.11p standard, oriented towards Wireless Access in Vehicular Environments (WAVE). It defines enhancements to 802.11, required to support Intelligent Transportation Systems (ITS) applications. This uses a similar physical layer to existing DSRC solutions, and operates in a similar frequency band, and as such could be seen as an enhancement to DSRC. Such enhancements include requirements for communication between high-speed vehicles and roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz).

Wired technologies (e.g., DSL, FTT, GPON) are currently used to include producer-consumer households and transformer stations in the grid infrastructure. Re-utilization of existing infrastructures is a cost effective solution compared to novel communication infrastructure deployment. Wired ICT, usually provides comparable data rate transmission

6.3 Market Readiness

The main suppliers of charging infrastructure technology were surveyed with a view to establishing the ability of the market to supply charging solutions. The market readiness was assessed by evaluating the Technology Readiness Level (TRL) and Market Readiness Level (MRL) of the various connected and wireless technologies available.

Static wireless charging is a technologically mature solution which has been tested extensively and the related products are ready to reach the market. Major vehicle manufacturers and OEMs are expected to provide wireless charging stations and EVs within the next one or two years.

Stationary wireless charging is a technologically mature solution which has been extensively tested for buses. The EVs and infrastructure products are already marketable and their commercial exploitation has begun.

With the exception of one supplier, the dynamic charging technology is still in R&D phase.

Conductive dynamic charging has been out of the lab environment and is being tested on regular roads. However commercialization is expected to take more time due to the significant investments required to transform normal roads to electric roads.

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ANNEX: WIRELESS POWER TRANSFER THEORY

When two coils are placed in close proximity as shown in Figure 52, an alternating current flowing in the first coil (Coil 1, the primary coil) will create alternating magnetic lines of flux as shown by the blue arrows, which in turn will induce a voltage in the second coil (Coil 2, the secondary coil). As the two coils are not in electrical contact, power is being transmitted wireless between the coils. This is the same principle that is used in transformers

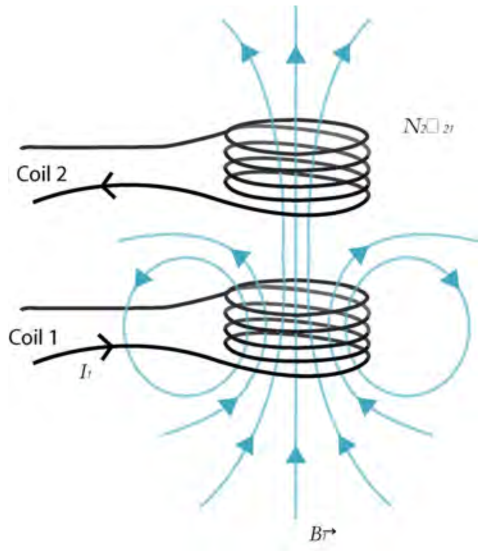

Figure 52: Varying current generates changing magnetic flux in coil 2 (MIT, 2014)

The efficiency of the power transfer is determined by the coupling coefficient between the coils. The coupling coefficient is largely dependent on the material around which the coils are wrapped, and the spacing between the coils. In transformers, the coupling coefficient is significantly enhanced by winding the coils around an iron (or similar material) core, and keeping the windings in very close proximity, often winding one coil on top of the other.

When used in a moving vehicle environment, it is clearly not possible to link the coils by means of a solid core, nor to place the coils in very close proximity. A transformer operating without a solid core is called an air-cored transformer.

The efficiency of power transfer in air-cored transformers can be increased by operating them at a much higher frequency than the 50 or 60 Hz typically used in mains power generation and distribution. For this reason, wireless power transfer systems typically operate at tens or even hundreds of kHz. To minimise the loss caused by the air gap between the primary and

secondary coils, static wireless power transfer systems will often make one of the coils, usually the secondary, moveable so that the gap between them is minimised during operation.

In dynamic charging systems, safety considerations require that a significant air gap is maintained between the primary and secondary coils. The efficiency of air cored transformers with a significant air gap can be dramatically improved by operating them in a resonant mode. This requires that each the primary and secondary coils form part of a tuned circuit, and that the two tuned circuits have the same resonant frequency.

Creating a tuned circuit is done by introducing capacitance to both the primary and secondary circuits, such that the capacitor forms a tuned circuit with the inductance of the transformer coils. The addition of this capacitance is called compensation.

Four compensation topologies are commonly used, namely series-series, series-parallel, parallel-series and parallel-parallel. These are described below.

Figure 53 shows the Series-Series compensation diagram. In this topology the output behaves like a current source, the power factor of the series-series compensation topology is unaffected by the distance between the coils. This means that the topologies with a series compensated primary side are well suited for transferring large amounts of power over relatively large distances.

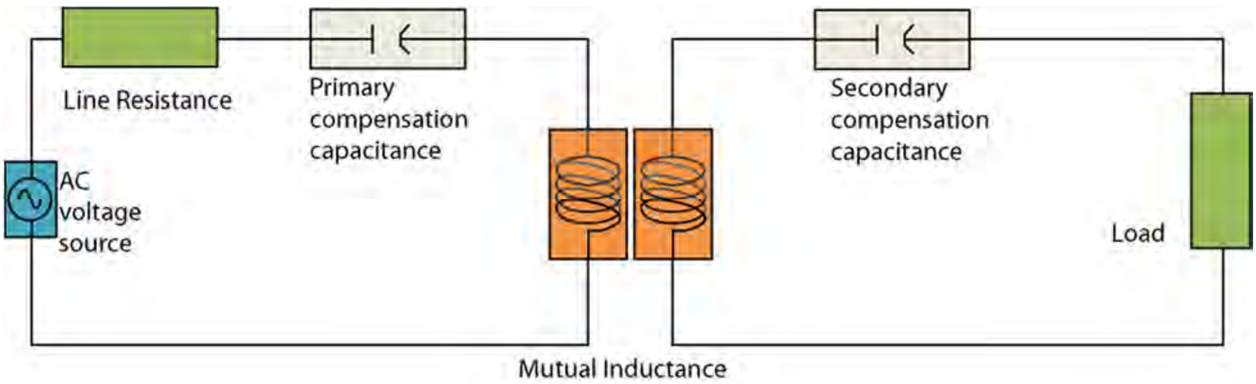

Figure 53: Series-Series Compensation

Figure 54 is the diagram for Series-Parallel compensation; this form of compensation acts as a voltage source, generating a constant voltage at the output.

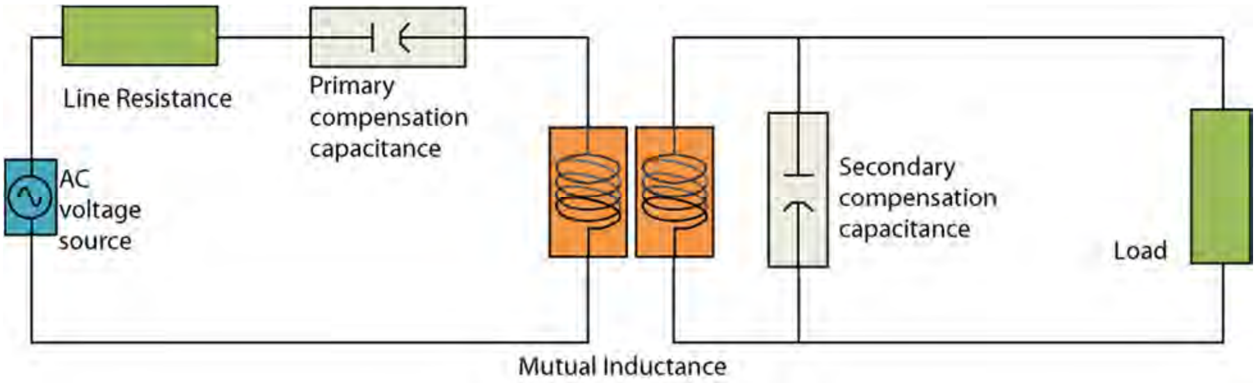

Figure 54: Series-Parallel Compensation

The topologies with a parallel compensated primary side are less sensitive to a decreased distance between the two coils compared topologies with a series compensated primary side. The efficiency is higher when the two coils are closer to each other. The power factor reduces when the distance between two coils is larger, and so is the efficiency. In smaller air gaps the output power increases, this means that the topologies with a parallel compensated primary side are well suited for transferring large amount of power over small air gaps (Cederlof, 2012).

Figure 55 shows the Parallel-Parallel compensation, this compensation topology acts like as a current source; the topology has constant output current.

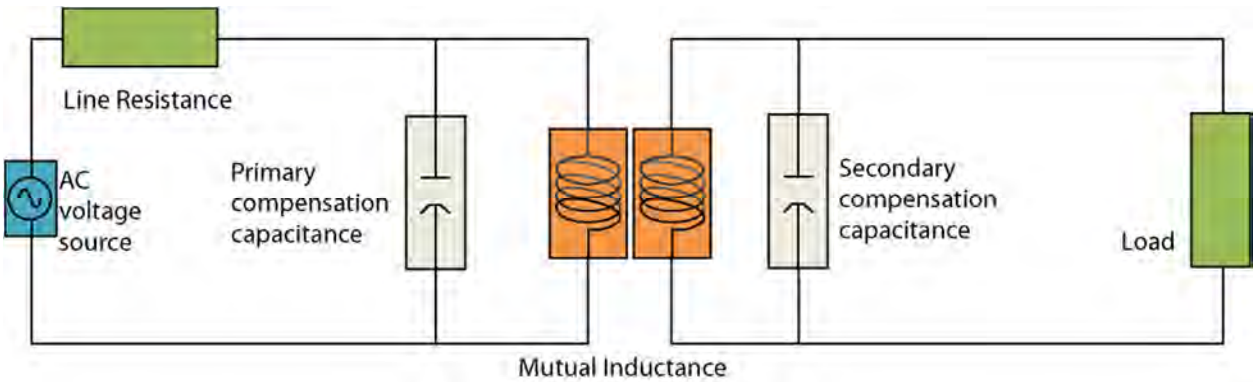

Figure 55: Parallel- Parallel Compensation

Figure 56 shows parallel series compensation, the output acts as a constant voltage source. When the primary side is in parallel, primary coil current is independent of primary capacitance, however, variation in capacitance will take the circuit out of resonance.

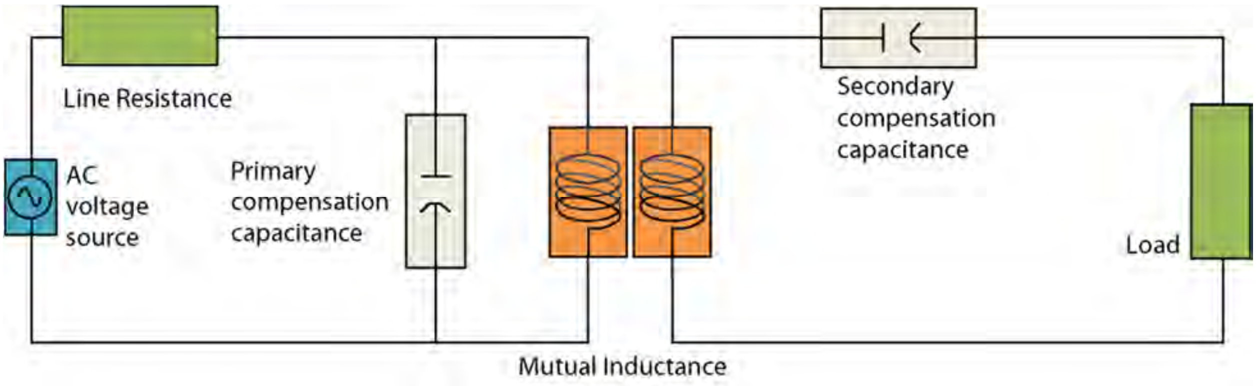

Figure 56: Parallel-Series Compensation

Series-Series and Parallel-Parallel compensation topologies have higher efficiency when compared to Series-Parallel and Parallel-Series compensation topologies. Parallel compensation uses less coil turns, hence lower inductance but, at same time draws a larger reactive current; therefore the compensation capacitor should have sufficient capacity to absorb large reactive currents.

Table 16 summarises the characteristics of the various compensation schemes.

Table 16: Topology Comparison (Venugopal Prasanth, 2012)

Topology	SS	SP	PS	PP
Output	Current source	Voltage Source	Voltage Source	Current Source
Power Factor at increasing distance	Very high	high	Medium	medium
Efficiency	Very high	Medium	Medium	High
Circuit impedance at Resonance	Minimum	Minimum	Maximum	Maximum
Power Transfer at constant source Voltage	Low	High	Low	High
Peak Efficiency	High	Low	High	Low
Tolerance of efficiency due to Variable frequency	Low	High	Low	High
Tolerance of power factor due to Variable frequency	High	Low	High	Low

The choice of compensation topology is dependent on efficiency, tolerance to frequency variation, power factor, load and air gap between two coils.

In the primary series topologies, the load is independent of compensation capacitance; this is an ideal case when the loading is variable. SP can transfer high power at low voltage and high current whereas SS require high voltage to transfer high power due to its high impedance at resonance. However, SS is more suitable option if the frequency of the system is driving factor as SS systems have higher maximum efficiency and higher tolerance for power factor in variable frequencies.

In primary parallel topologies, compensation capacitance changes with variable load. PS topology has higher peak efficiency and better tolerance to power factor when compared with PP topology. (Prasanth, 2012)

ANNEX: STANDARDS

IEC 61000-3-4

IEC61000-3-4 defines limits for levels of harmonic current in equipment rated above 16A with nominal voltage up to 600V, 3 phases.

Table 17: Limits for stage 1 (%)

I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	THD	PWHD
4	21.6	2	10.7	1.3	7.2	1	3.8	0.8	3.1	0.7	2	23	23

The values are percentage relative to fundamental waveform. The equipment will be conforming with IEC 61000-3-4 if all the measured values are below the values stated in table 2 and $R_{sce\ min}$ = 33.

$$R_{sce\ min} = \frac{230}{Z \times I_{equ}}$$

Where:

Z=supply output impedance,

Iequ= rated line current

If the system does not meet the requirements in stage 1, compare the measured values against the appropriate connection type in Table 18, the measured has be lower that stated values in the table for given min Rsce min.

Table 18: Stage 2 limits

Min R_{sce}	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	THD (%)	PWHD (%)
Balanced three phase														
33	8		4	10.7	2.7	7.2	2		1.6	3.1	1.3	2	13	22
66	8		4	14	2.7	9	2		1.6	5	1.3	3	16	25
120	8		4	19	2.7	12	2		1.6	7	1.3	4	22	28
250	8		4	31	2.7	20	2		1.6	12	1.3	7	37	38
350	8		4	40	2.7	25	2		1.6	15	1.3	10	48	45

Equipment other than three phase														
33	8	21.4	4	10.7	2.7	7.2	2	3.8	1.6	3.1	1.3	2	23	23
66	8	24	4	13	2.7	8	2	5	1.6	4	1.3	3	26	26
120	8	27	4	15	2.7	10	2	6	1.6	5	1.3	4	30	30
250	8	35	4	20	2.7	13	2	9	1.6	8	1.3	6	40	40
350	8	41	4	24	2.7	15	2	12	1.6	10	1.3	8	47	47
Balanced Three-phase Equipment Under Specified Conditions														
33	8		4	10.7	2.7	7.2	2		1.6	3.1	1.3	2	13	22
120	8		4	40	2.7	25	2		1.6	15	1.3	10	48	45

Stage 3 is approval from distribution network operator to connect the equipment as the equipment does not comply with IEC 61000-3-4 requirements.

IEC 61000-3-5

IEC 61000-3-5 covers the limitation of voltage fluctuations and flicker in low voltage power supply systems for equipment with rated current greater than 16 A

IEC 61000-6-1

Electromagnetic compatibility (EMC) part 6-1 is titled “Generic standards -Immunity for residential, commercial and light-industrial environments” this standard applies to the equipment’s installed in public areas, in order to confirm with IEC 61000-6-1 the system has to comply with following standards: 61000-4-2, 61000-4-3, 61000-4-4, 61000-4-5, 61000-4-6, 61000-4-8, 61000-4-11.

Table 19: IEC 61000 standard

IEC 61000-6-3

IEC 61000-6-3 is titled Generic standards—Emission standard for residential, commercial and light-industrial environments. The standard defines the emission test requirements of the equipment.

ANNEX: COMMUNICATION

This appendix includes detailed descriptions of some relevant communications technologies.

7.1.1 Lower Layer communication technologies

Bluetooth	
Full Name / Standard	Bluetooth
Specification-/ Standardisation-Body / Patents	Bluetooth Special Interest Group (SIG), originally created by Ericsson IEEE 802.15.1 - standard is no longer maintained
Summary / Short profile	Bluetooth is a wireless, low power and data rate, technology designed for short range, i.e. personal area network (PAN), communications. It is maintained by the Bluetooth Special Interest Group (SIG) with more than 18.000 members. The standard operates in the 2400-2480 MHz ISM band and uses frequency-hopping spread spectrum with 1600 hops per second in order to increase its resilience against e.g. interference. There are 79 channels, each 1MHz wide. The modulation is dependent on the channel quality and the version of the standard. A Master-Slave architecture (up to 7 slaves per master) is used and the data exchange is packet based. **Technical features:** Data rate (up to - depending on transfer modus, version, channel quality): - 1 Mbps (V1.2) - 3 Mbps (V2.0) - 24 Mbps (V3.0) Range and transmission power: - Class 3: 1 mW (0dBm), 1m - Class 2: 2,5 mW (4dBm), 10m - Class 1: 100 mW (20dBm), 100m Frequency band: 2,4 GHz ISM-band

	Connection types: - Synchronous Connection-Oriented – SCO - Asynchronous Connectionless – ACL Security: - Pin based key generation (SAFER+ block cipher) - Security Manager - AES encryption (V4) - Authentication - Confidentiality

EnOcean	
Full Name / Standard	EnOcean
Specification-/ Standardisation-Body / Patents	EnOcean GmbH ISO/IEC 14543-3-10
Summary / Short profile	Enocean is a very low power, short range communication technology. It can use energy harvesting as a power source and thus requires little to no maintenance and no power cabling. It is mostly designed for in-house applications like home automation. Frequency bands: 315 MHz / 868,3MHz Data rate: 125kbit/s (ASK) Range: - up to 300m (line-of-sight) - up to 30 m (in buildings) Security: - 32-bit Message authentication code - AES128 encryption - ARC4 with 32 bit key

Ethernet	
Full Name / Standard	Ethernet
Specification-/ Standardisation-Body / Patents	Institute of Electrical and Electronics Engineers, IEEE IEEE 802.3
Summary / Short profile	Ethernet is a wired networking technology originally used for LANs. IEEE 802.3 is a well-known standard that goes back to 1970s when a first experimental version was realized. This standard is based on the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) in which all the devices connected to the network have access to the transmission medium and can send and receive data whenever the network is idle. **Technical features:** Data rate (symmetrical): - 10Mbps - 100Mbps - 1Gbps - 10Gbps - 40Gbps - 100Gbps - (400Gbps and 1Tbps are in planning stages) Range: - up to 100m using copper cabling - up to 40km without repeater using optical cabling - up to 80km with optical cabling (phy not specified within IEEE802.3ae) The IEEE 802.3at-2009 standards allows the transmission of up to 25,5 W of power over (copper based) Ethernet cabling.

TTEthernet	
Full Name / Standard	TTEthernet

Specification-/ Standardisation-Body / Patents	SAE AS6802 TTTech Computertechnik AG
Summary / Short profile	TTEthernet is an IEEE 802.3 compatible Quality of Service extension of Ethernet which has been created in order to provide functionality for real-time applications such as a guaranteed service level and latency. It is thus used in safety critical environments such as airplanes or the automation industry. Fault-tolerance is also included in the specifications. Due to its Ethernet base many technological parameters, including data rate, cabling and topology are similar or identical.

WLAN	
Full Name / Standard	Wireless Local Area Network (WLAN) IEEE 802.11 (Wi-Fi)
Specification-/ Standardisation-Body / Patents	IEEE 802 Standards Committee (Wi-Fi Alliance)
Summary / Short profile	**Technical features:** Frequency band: - 2,4 GHz (IEEE 802.11 b/g/n) - 5 GHz (IEEE 802.11 a/n/ac) - 60 GHz (IEEE 802.11 ad) Data rate (up to, symmetrical): - 1 Mbps, 2 Mbps (original standard) - 54 Mbps (IEEE 802.11 a) - 11 Mbps (IEEE 802.11 b) - 54 Mbps (IEEE 802.11 g) - 600 Mbps (IEEE 802.11 n) - 6,77 Gbps Mbps (IEEE 802.11 ac – 500Mbps per stream, typically 3 used) - 7 Gbps (IEEE 802.11 ad) Range:

	- up to 70m indoors and 100m outdoors (higher frequency bands limit the range further) - outdoors greater distances in the range of multiple km have been achieved with special antennas and higher transmission power Security: - WPA2 with AES encryption (FIPS 140-2 certified), TKIP and CCMP - PSK or RADIUS Authentication It is to be taken into account, that the specified speeds depend heavily on factors like spectrum usage, environment, line of sight and signal power, transceiver/receiver quality. This is the case for all wireless technologies. Additionally the values presented above are phy-link rates and do not match the achievable throughput on application layer level.

ZigBee	
Full Name / Standard	ZigBee
Specification-/ Standardisation-Body / Patents	IEEE 802.15.4 The ZigBee technology is maintained by the ZigBee Alliance.
Summary / Short profile	ZigBee is a radio technology for low-cost wireless links with reduced energy consumption. It is therefore particularly adapted to in-house electronic appliances. This technology allows short-range transfer (2,5 MHz, 16 channels) at relatively low rates (250 Kbit/s at a maximum distance 100 m). The standard is based on IEEE 802.15.4 and uses a mesh topology. ZigBee also defines a Smart Energy profile available in version 2.0. It is an IP based protocol for smart grid purposes as meter reading and EV charging communication.

Z-Wave	
Full Name / Standard	Z-Wave

Specification-/ Standardisation-Body / Patents	Z-Wave Alliance
Summary / Short profile	Z-Wave is a wireless communication standard with limited data rate and range. **Technical features:** Frequency band: - 868,42 MHz SRD Band (Europe – 1% duty cycle) - 900 MHz ISM Band Data rate: up to 100kbps (9,6 and 40kbps modes available) Range: 30 m (line of sight), less indoors Max. number of devices per network: 232 (more when using bridges) Architecture: Master - Slave

7.1.2 Wide area network

EDGE	
Full Name / Standard	Enhanced Data Rates for GSM Evolution Further names: Enhanced Circuit Switched Data (ECSD) Enhanced General Packet Radio Service (EGPRS)
Specification-/ Standardisation-Body / Patents	3GPP TR50.059
Summary / Short profile	EDGE is a 2.5G enhancement of GSM/GPRS cellular networks which increases the data rate by use of 8PSK modulation. **Technical features:** Data rate: up to 476,6 Kbps, 100-300 Kbps (typical) Coverage: 35km (max), 3-10km (typical) Frequency bands: - Uplink: 880-915 MHz. 1710-1785 MHz - Downlink: 925-960 MHz, 1808-1880 MHz Licensing: Exclusive spectrum allocation by ITU and national bodies (BNetzA in Germany)

	Security: - Prone to MITM attacks (IMSI catcher) - A5/1 encryption broken Extensions: Evolved EDGE

GPRS	
Full Name / Standard	General Packet Radio Service (GPRS)
Specification-/ Standardisation- Body / Patents	3GPP, originally ETSI
Summary / Short profile	Technical features: Data rate: up to 476,6 Kbps, 100-300 Kbps (typical) Coverage: 35km (max), 3-10km (typical) Frequency bands: - Uplink: 880-915 MHz. 1710-1785 MHz - Downlink: 925-960 MHz, 1808-1880 MHz Licensing: Exclusive spectrum allocation by ITU and national bodies (BNetzA in Germany) Security: - Prone to MITM attacks (IMSI catcher) - A5/1 encryption broken Extensions: Increased data rate through enhanced modulation (EDGE)

GSM	
Full Name / Standard	Global System for Mobile Communications (GSM) Originally: Groupe Spécial Mobile
Specification-/ Standardisation-Body / Patents	3GPP, originally ETSI

Summary / Short profile	**Technical features:** Data rate: up to 9,6 Kbps Coverage: 35km (max), 3-10km (typical) Frequency bands: - Uplink: 880-915 MHz. 1710-1785 MHz - Downlink: 925-960 MHz, 1808-1880 MHz Licensing: Exclusive spectrum allocation by ITU and national bodies (BNetzA in Germany) Security: - Prone to MITM attacks (IMSI catcher) - A5/1 encryption broken - No data integrity - No end-to-end encryption Extensions: - Packet switched data (GPRS) - Increased data rate through enhanced modulation (EDGE)

HSPA / HSPA+	
Full Name / Standard	High Speed Packet Access: - High Speed Downlink Packet Access (HSDPA) - High Speed Uplink Packet Access (HSUPA) - Dual-Carrier HSDPA (DC-HSDPA) - Dual-Carrier HSUPA (DC-HSUPA) - Multi-Carrier HSPA (MC-HSPA) - Evolved High Speed Packet Access (HSPA+)
Specification-/ Standardisation-Body / Patents	3GPP Rel. 5-11
Summary / Short profile	HSPA is a family of packed switched 3.5G mobile communication standards by 3GPP. They provide higher data rates than UMTS which they extend and improve upon. This is achieved by techniques like higher order modulation, MIMO, fast scheduling and link adaption. **Technical features:**

	Data rate: - HSDPA: up to 42 Mbps (Downlink) - HSUPA: up to 23 Mbps (Uplink), 5,76 Mbps (typical) - DC-HSDPA: up to 84 Mbps (Downlink) - DC-HSUPA: up to 46 Mbps (Uplink) - MC-HSPA: up to 672 Mbps (Downlink) - HSPA+: 337 Mbps (Downlink), 22 Mbps (Uplink) Coverage: 8 km (max), 2-3km (typical) Frequency bands: - TDD: 1900-1920 MHz, 2010-2025 MHz, 2570-2620 MHz - FDD (Uplink): 832-862 MHz. 880-915 MHz, 1710-1785 MHz, , 1920-1980 MHz - FDD (Downlink): 791-821MHz, 925-960 MHz, 1805-1880 MHz, 2110-2170 MHz Licensing: Exclusive spectrum allocation by ETSI and national bodies (BNetzA in Germany) Security: - Mutual authentication - 128Bit Encryption - End-to-end encryption - Data integrity

LTE / LTE Advanced	
Full Name / Standard	Long Term Evolution / Long Term Evolution Advanced Further names: Evolved UTRAN
Specification-/ Standardisation-Body / Patents	3GPP LTE: 3GPP Rel.8 LTE-A: 3GPP TR 36.913

Summary / Short profile	Long Term Evolution (LTE) is a 3.9G mobile communication standard which has been deployed since 2010. Its enhancement Long Term Evolution Advanced (LTE-A) is a 4G mobile communication standard which will be rolled out starting approximately 2013. Frequently a software update of LTE base stations (e-NodeB) is sufficient to enable LTE-A support from the network side. Both standards focus primarily on data instead of voice services. **Technical features:** Data rate: - Downlink: up to 300 Mbps (LTE) – up to 3Gbps (LTE-A) - Uplink: up to 75 Mbps (LTE) – up to 1,5Gbps (LTE-A) Coverage: 100km (max), 2-3km (typical) Frequency bands: - TDD: 1900-1920 MHz, 2010-2025 MHz, 2570-2620 MHz - FDD (Uplink): 832-862 MHz. 880-915 MHz, 1710-1785 MHz, , 1920-1980 MHz, 2500-2570 MHz - FDD (Downlink): 791-821MHz, 925-960 MHz, 1805-1880 MHz, 2110-2170 MHz, 2620-2690 MHz Licensing: Exclusive spectrum allocation by ETSI and national bodies (BNetzA in Germany) Security: - Mutual authentication - 128Bit Encryption - End-to-end encryption - Data integrity Extensions: Machine Type Communication (MTC) or Machine to Machine (M2M) communication is supported.

UMTS	
Full Name / Standard	Universal Mobile Telecommunications System
Specification-/ Standardisation-	3GPP TS 25Series Rel. 99, originally ETSI

Body / Patents	
Summary / Short profile	The Universal Mobile Telecommunications System (UMTS) is a 3G cellular mobile communication standard which has been deployed since 2002. It utilizes Wideband Code Division Multiple Access (W-CDMA) to increase data rates above GSM level. Ahead of transmission spread-spectrum is applied to the data which raises its robustness against narrowband interference. This code multiplexed multiple access strategy allows all users to transmit on the same frequency, thereby creating the need for strict signal power management. The data rate is also affected by this technique in that all users of a cell share the total available spectrum at all times. As a result the cell size varies dynamically, shrinking as the number of users per cell rises. This is called “cell breathing”. Additionally eavesdropping, fading and jamming are hindered by the use of spread-spectrum. **Technical features:** Data rate: - Up to 384 kbps (mobile) - Up to 2 Mbps (stationary) Coverage: 8 km (max), 2-3km (typical) Frequency bands: - TDD: 1900-1920 MHz, 2010-2025 MHz, 2570-2620 MHz - FDD (Uplink): 832-862 MHz. 880-915 MHz, 1710-1785 MHz, , 1920-1980 MHz - FDD (Downlink): 791-821MHz, 925-960 MHz, 1805-1880 MHz, 2110-2170 MHz Licensing: Exclusive spectrum allocation by national bodies (BNetzA in Germany) Security: - Mutual authentication - 128 Bit A5/3 encryption - End-to-end encryption - Data integrity Extensions: increased data rate through improved modulation,

	see HSPA and HSPA+

WiMAX	
Full Name / Standard	Worldwide Interoperability for Microwave Access (WiMAX)
Specification-/ Standardisation-Body / Patents	IEEE 802.16 ITU-R M.1457 WiMAX Forum
Summary / Short profile	WiMAX is a Wireless Metropolitan Area Network (W-MAN) standard specified by IEEE 802.16. Two sub standards exist, a mobile and a fixed version which are specifically geared towards their respective use cases. The WiMAX Forum has published three licensed frequency bands, 2,3 GHz, 2,5 GHz and 3,5 GHz. However, no globally uniform licensed spectrum is available. MIMO, Orthogonal Frequency Division Multiplexing (OFDM), hybrid automatic repeat-request as well as Quality-of-Service (QoS) and adaptive modulation are among the technical features of WiMAX. Release 2, also known as Mobile WiMAX 2, as specified by IEEE 802.16m is classified by the International Telecommunications Union (ITU) as a 4G mobile communication standard. Operators of WiMAX networks can upgrade to Release 2 specifications either by software or new channel cards. **Technical features:** Data rate: - Downlink: Up to 15 Mbps (Rel.1, mobile) Up to 70 Mbps (Rel.1, fixed)

	▯ Up to 365 Mbps (Rel.2, FDD, mobile) ▯ Up to 1 Gbps (Rel.2, FDD, fixed / low mobility) - Uplink: ▯ Up to 17 Mbps (Rel. 1) ▯ Up to 376 Mbps (Rel.2, FDD) Coverage: 50 km (max), 2-5 km (typical) Mobility: connectivity up to 500 km/h depending on frequency band used, up to 350 km/h typically with reduced throughput Frequency bands: - No globally uniform licensed spectrum available - 3,5 GHz Band (Austria, Germany, Italy, Portugal) - Possible reallocation of 500-800 MHz spectrum for technologies including WiMAX in the EU Licensing: Exclusive spectrum allocation by national bodies (BNetzA in Germany) Security: - Built-in support for X.509 device certificates - EAP-TLS authentication in 802.16e - DES, 3DES, AES (up to 256 bit) encryption supported Miscellaneous: supports mesh networking, QoS support, minimum guaranteed throughput

xDSL	
Full Name / Standard	Asymmetric Digital Subscriber Line (ADSL) Asymmetric Digital Subscriber Line 2 (ADSL2) Extended bandwidth Asymmetric Digital Subscriber Line 2 (ADSL2+) High-bit-rate Digital Subscriber Line (HDSL) High-bit-rate Digital Subscriber Line 2 (HDSL2) Symmetric Digital Subscriber Line (SDSL) Single-pair High-speed Digital Subscriber Line (SHDSL) Very-high-bit-rate Digital Subscriber Line (VDSL)

	Very-high-bit-rate Digital Subscriber Line 2 (VDSL2)
Specification-/ Standardisation-Body / Patents	ANSI T1.413-1998 (ADSL) ETSI TS 101952-1-4 (ASDL over ISDN or POTS) ITU G.992.1 (ADSL) ITU G.992.2 (ADSL Lite) ITU G.992.3 (ADSL2) ITU G.992.5 (ADSL2+) ITU G.991.1 (HDSL) ITU G.991.2 (SHDSL) ITU G.993.1 (VDSL) ITU G.993.2 (VDSL2)
Summary / Short profile	The family of Digital Subscriber Line (xDSL) standards describes ISO-OSI layer 1 technologies which provide connectivity over wires of the telephone network. Concurrent use of analogue or digital (ISDN) telephone services and DSL is possible. The most commonly used versions are Asymmetric Digital Subscriber Line (ADSL) and ADSL2, which owe their name to the fact that the downlink provides a higher bandwidth than the uplink. VDSL sees increasing deployment as the bandwidth requirements of end-users continues to rise. The achievable data rate is dependent on the quality of the telephone cable and decreases as the distance from DSL modem to the provider equipment (DSLAM) increases. DSL technologies are the most widely deployed Internet access technologies in the EU. Flat rates are available at relatively low costs. **Technical features:** Data rate (up to): - ADSL: 12 Mbps (Downlink), 1,8 Mbps (Uplink) - ADSL2: 12 Mbps (Downlink), 3,5 Mbps (Uplink) - ADSL2+: 24 Mbps (Downlink), 3,3 Mbps (Uplink) - HDSL: 2 Mbps (Down- and Uplink) - SHDSL: 2312 Kbps, 5696 Kbps in extended mode (Down- and Uplink) - VDSL: 55 Mbps (Downlink), 3 Mbps (Uplink) - VDSL2: 100 Mbps (Down- and Uplink)

	Coverage: - <4 km (typical) - <500 m (max. throughput), dependent on wire quality (i.e. shielding, material, diameter) Frequency Bands: - ADSL: 25 kHz to 138 kHz or 138 kHz to 276 kHz (Uplink), 138 kHz to 1,1 MHz (Downlink) - ADSL2+: 138 kHz to 276 kHz (Uplink), 276 kHz to 2,2 MHz (Downlink) - VDSL: 25 kHz to 12 MHz Physical medium: 2-wire telephone lines

NPLC	
Full Name / Standard	Narrow-band Power line Communications
Specification-/ Standardisation-Body / Patents	CENELEC SC205AISO/IEC JTC 1, IET TC57, CECED EN 50065-x (Mains Signalling) ISO/IEC 14543-x (Smart home) IEC 613334-x (Distribution automation) CHAIN Standard (CECED)
Summary / Short profile	Narrow-band Power line Communications uses existing power lines as transmission medium. Therefore if electric power supply is given it is not necessary to install new wires. Narrowband PLC (NPLC) is a technology which consists of building the access network over the infrastructure of the LV and MV network achieving bit rate that does not exceed the 500kbps. It operates in any of the VLF/LF/MF bands (from 3 kHz to ~500 kHz) which include the CENELEC/FCC/ARIB bands. Based on the same philosophy as DSL technique, which uses the high frequencies of an already existing medium used by other low-frequency services, the PLC systems use a high frequency band on the energy cables on which the electricity signal is transported over the 50Hz. For the NPLC the spectrum part, 9kHz to 148.5kHz is reserved. Technical features:

	Frequency band - From 3kHz up to 148,5kHz Data rate - 1bps up to 10kbps up to 500kbps

7.1.3 Higher Layer Communication Protocols

6LoWPAN	
Full Name / Standard	IPv**6** over **Lo**w power **W**ireless **P**ersonal **A**rea **N**etworks.
Specification-/ Standardization-Body/ Patents	IETF Last Request for Comments: 4944 September 2007
Summary / Short profile	The purpose of 6LoWPAN is to allow IPv6 packet exchange through low-rate/ lossy personal area networks in order to adapt them for transmission into an IEEE 802.15.4 frame (only 128 bytes). **Functions:** - Stateless auto-configuration - Adaptive mechanism with header stack (within optional routing information) to describe packet type - Packet header compression to fit into LLN frames - Packet fragmentation and reassembly - Routing inside/outside PAN - Supporting AES (Advanced Encryption Standard) cryptography mechanisms.

ETSI M2M Functional architecture	
Specification-/ Standardization-Body/ Patents	**ETSI** Technical Specification 102 690 V1.1.1 (2011-10)
Summary / Short profile	ETSI M2M functional architecture consists of the connection between M2M service capabilities layer of a M2M gateway or device and the Network domain ones. M2M service capabilities are accessed by M2M applications implemented on the devices. M2M Service Capabilities:

	- Provide M2M functions that are to be shared by different Applications. - Expose functions through a set of open interfaces. - Use Core Network functionalities (ip connectivity, interconnection, , … N b G N , ETSI TISPAN CN and 3GPP2 CN) - Simplify and optimize application development and deployment through hiding of network specificities. M2M SCs can use Core Network functionalities through a set of exposed interfaces (e.g. existing interfaces specified by 3GPP, 3GPP2, ETSI TISPAN, etc.). Additionally, M2M SCs can interface to one or several Core Networks. The list of M2M Service Capabilities is provided below: - Application Enablement - Generic Communication - Reachability, Addressing and Repository - Communication Selection - Remote Entity Management - Security - History and Data Retention - Transaction Management - Compensation Broker - Telco Operator Exposure - Interworking Proxy Logical interaction among M2M SCLs or between M2M SCL and M2M applications are registration/authentication function, read/write commands, notification events or device management actions (e.g. software upgrade, configuration management)

ETSI M2M Interface descriptions	
Specification-/ Standardization-Body/ Patents	**ETSI** Technical Specification 102 921 V1.1.1 (2012-02)
Summary / Short profile	The M2M system is (web) resource based and the interfaces to access these resources among Service Capabilities or between SC and M2M GW application are made by methods. Each method (for example an UPDATE) conveys a set of information defined as method attributes (for example a parameter to be updated).

	A resource is a uniquely addressable entity in the RESTful vocabulary. Each resource has a representation that shall be transferred and manipulated with the verbs. A resource shall be addressed using a Universal Resource Identifier (URI). To perform interface communication a M2M system commonly uses: - Primitives. - Data type definitions. - Mapping to HTTP and CoAP (to transfer data into a LLN). - XML definitions of the resources (for example for device self-description). - Security procedures.

ETSI M2M Service requirements	
Specification-/ Standardization-Body/ Patents	**ETSI** Technical Specification 102 689 V1.1.1 (2010-08)
Summary / Short profile	The M2M System shall be able to allow communication between M2M Applications in the Network and Applications Domain, and the M2M Device or M2M Gateway, by using multiple communication means, e.g. SMS, GPRS and IP Access. **General requirements:** - Supporting anycast, unicast, multicast and broadcast communication modes, also towards sleeping devices. - Managing the scheduling of network access and of messaging, being aware of the scheduling delay tolerance of the M2M Application - Enabling routing methods to optimize data exchange according to network (low-rate) nature and policy and to solve/prevent delays or failure issues. On-going communications may also be interrupted in order to serve a flow with higher priority - Scalability and interoperability - Supporting M2M Service Capabilities offered to M2M applications - Authentication/confirmation mechanisms and integrity checks for security, as well as methods to perform continuous connectivity - Enabling anonymisation of a particular device, subject to its

	request to the network that takes care to fulfil it. On the other side, M2M system shall be able to realize locating mechanisms for both M2M GW and devices - Providing real-time management of radio transmission between M2M GW-side and connected M2M devices on the network - M2M interface to the external M2M applications shall enable the exposition of telco operator capabilities (e.g. SMS, USSD, localization, subscription configuration, authentication - e.g. Generic Bootstrapping Architecture, etc.). The service platform shall be able to provide access to non-M2M resources abstracted as M2M resources to provide to the applications a consistent use of the M2M capabilities (e.g. to send an SMS to common cellular phones). - Diagnostic tests and procedures; failure discovery and recovery - SLA monitoring and support to QoS capabilities - Data collection and reporting - Multiple M2M Devices/GWs management and self-description - Allowing flexible addressing schemes (IP, multicast address, MSISDN).

HTTP	
Full Name / Standard	HyperText Transfer Protocol
Specification-/ Standardization-Body/ Patents	IETF and W3C HTTP/1.1 is specified in RFC 2616
Summary / Short profile	HTTP is an application layer protocol that provides a structural way of exchange information between servers and clients, i.e. it follows a request-response type of interaction pattern. HTTP specifies a set of request methods that the client can use to interact with the server. The protocol is widely used for web browsing and as such standard, well tested implementation of this protocol exists. Therefore, the main potential usage for this protocol would probably be on the WAN side of the SmartC2Net system, where several servers need to interact over public IP based networks

IEC / ISO 15118	
Full Name / Standard	ISO/IEC 15118 Road Vehicles - Vehicle to Grid Communication Interface
Specification-/ Standardization-Body/ Patents	International Standardization Organization (ISO) International Electrotechnical Commission (IEC)
Summary / Short profile	A Joint Working Group (JWG) between ISO and IEC was formed in 2009 in order to specify the V2G Communication Interface for Battery Electric Vehicles. Its purpose is to define a bidirectional IP-based communication protocol complementary to the low level signalling defined in IEC 61851-1. The JWG started defining the first three parts in 2009. Part 1 of the standard (ISO/IEC 15118-1) defines all relevant terms for the V2G Interface and provides basic definitions and use cases being considered as part of the specification. It was published as an international standard in early 2013. The subsequent technical specifications for conductive charging are defined in ISO/IEC 15118-2 and ISO/IEC 15118-3 and are still work in progress. Part 2 defines the IP binding process, complete message flows and data types for AC and DC charging between communication controllers in EVs (EVCC) and charge spots (SECC) and cover ISO/OSI layers 3-7. Part 3 defines the physical and data link layer requirements of the power line communication based carrier technology including the association process. The envisioned high level communication protocol will allow for advanced interaction between the grid and connected EVs for authentication & authorization, accounting, load levelling management and further added-value services. The primary scope of the standard is limited to the communication between the EVCC and SECC. (As follow-up to the first three parts, the JWG started new projects in 2012 to define conformance tests of the technical specifications as part of ISO/IEC 15118-4 (part 2 conformance tests) and ISO/IEC 15118-5 (part 3 conformance tests). Further work was also started for the definition of wireless physical and data link layers of the V2G Communication Interface in ISO/IEC 15118-8. Next to communication means for inductive charging scenarios, such an alternative carrier will also bring along new use cases even for conductive charging scenarios. A

	complementary set of use cases suitable for wireless carriers are therefore defined in ISO/IEC 15118-6. An additional alignment specification targeting document ISO/IEC 15118-7 will introduce all differences and new message sets compared to the core message specification (ISO/IEC 15118-2) in power line communication based scenarios. However, all these parts are in very early stages of the standardization process.)

IEC 60870	
Full Name / Standard	Telecontrol equipment and systems
Specification-/ Standardization-Body/ Patents	IEC 60870 The 60870 standards are developed by IEC Technical Committee 57 (Working Group 03).
Summary / Short profile	In electrical engineering and power system automation, the International Electrotechnical Commission 60870 standards define systems used for telecontrol (supervisory control and data acquisition). Such systems are used for controlling electric power grids and other geographically widespread control systems. By use of standardized protocols, equipment from many different suppliers can be made to interoperate. IEC standard 60870 has six parts, defining general information related to the standard, operating conditions, electrical interfaces, performance requirements, and data transmission protocols. IEC 60870-5 provides a communication profile for sending basic telecontrol messages between two systems, which uses permanent directly connected data circuits between the systems. Five documents specify the base IEC 60870-5: - IEC 60870-5-1 Transmission Frame Formats - IEC 60870-5-2 Data Link Transmission Services - IEC 60870-5-3 General Structure of Application Data - IEC 60870-5-4 Definition and Coding of Information Elements - IEC 60870-5-5 Basic Application Functions IEC 60870-5-101/102/103/104 are companion standards generated for basic telecontrol tasks, transmission of integrated totals, data exchange from protection equipment & network access of IEC101 respectively. In particular IEC 60870-5-104 was published in order to

	migrate from IEC 60870-5-101, based on serial communication, to the telecontrol via IP-networks. Every telecontrol station conforming to the IEC 60870-5-104 standard has an Internet Transport Interface between its application layer and the layers below. The interface and the lower layers are defined by the appropriate Internet standards. These include the Transmission Control Protocol (TCP), for the Transport layer immediately below the Transport Interface. IEC TC 57 WG3 also generated standards for telecontrol protocols compatible with ISO standards and ITU-T recommendations.

IEC 61850	
Full Name / Standard	Communication networks and systems for power utility automation
Specification-/ Standardization-Body/ Patents	IEC 61850 The 61850 standards are developed by IEC Technical Committee 57
Summary / Short profile	The standard IEC 61850 provides standardized communication in substations based on both state of the art communication technology and powerful object modelling. The approach of IEC 61850 is based on the separation between the object model (with data and services) and the ISO/OSI architecture in order to be technology independent and hence “future proof”. The object model is based on the fundamental brick that is called Logical Node. The Logical Node contains data that, in turn, contain attributes which may be seen as values or detailed properties of the data. Moreover, Logical Nodes can be grouped into Logical Devices with non-standardized names and then implemented in servers placed in the Intelligent Electronic Devices (IED). Between the object model and the communication technology, a middle layer is placed, named Specific Communication Service Mapping (SCSM). Summarizing the IEC 61850 features include: data modelling, reporting schemes, fast transfer of events, sampled data transfer, various command types including direct & select before operate commands with normal and enhanced securities, storage of the configured data. IEC 61850 series consists of ten parts (all parts may have not

	been published yet). The IEC 61850-7-x series of standards define the "basic communication structure for substation and feeder equipment". The approach is to define the abstract services and data objects in order to be technology independent. Given the data and services abstract definitions, the final step is to map the abstract services into an actual protocol. It could be done through the IEC 61850-8/9 series of standards.

IEC 62056	
Full Name / Standard	Electricity metering data exchange - The DLMS/COSEM suite
Specification-/ Standardization-Body/ Patents	IEC 62056 DLMS User Association (DLMS-UA)
Summary / Short profile	The DLMS/COSEM specifications specify communication protocols and data models to exchange data with metering equipment.

IEC 62351	
Full Name / Standard	Power systems management and associated information exchange - Data and communications security
Specification-/ Standardization-Body/ Patents	IEC 62351 The 62351 standard is developed by IEC Technical Committee 57 (Working Group 15)
Summary / Short profile	The scope of the IEC 62351 series is information security for power system control operations. "*Undertake the development of standards for security of the communication protocols defined by IEC TC 57, specifically the IEC 60870-5 series, the IEC 60870-6 series, the IEC 61850 series, the IEC 61970 series, and the IEC 61968 series. Undertake the development of standards and/or technical reports on end-to-end security issues.*" • IEC 62531-1 provides an introduction to the remaining parts of the standard, primarily to introduce the reader to various aspects of information security as applied to power system operations. • IEC 62351-3 to IEC 62351-6 specifies security standards for

	the IEC TC 57 communication protocols. These can be used to provide various levels of protocol security, depending upon the protocol and the parameters selected for a specific implementation. They have also been design for backward compatibility and phased implementations. • IEC 62351-7 addresses one area among many possible areas of end-to-end information security, namely the enhancement of overall management of the communications networks supporting power system operations. • Other parts are expected to follow to address more areas of information security.

OMA DM	
Full Name / Standard	**O**pen **M**obile **A**lliance **D**evice **M**anagement
Specification-/ Standardization-Body/ Patents	Open Mobile Alliance
Summary / Short profile	OMA DM is a protocol designed to manage many small mobile devices. This protocol defines the commands an OMA DM Server must send asynchronously to an OMA DM client such as reading or setting configuration as well as (un)installing or upgrading software instructions or fault notification and diagnostic tests. In broad terms, Device Management consists of three parts: Protocol and mechanism: the protocol used by a Management Server to communicate with the device. Data model: the representation of device data made available for remote manipulation, such as browser and mail settings. Policy: the policy decides who is allowed to manipulate a particular parameter or to update a specific Management Object (an integer as well as an URL) in the device. Moreover, OMA DM provides methods of checking, authentication and encryption for both client and server to ensure protection and integrity of data exchange, because of OMA DM purpose to connect such a large number of devices which could send themselves confidential data.

	OMA DM messages – like a Management Tree, the mechanism used by the client to describe itself to the server – are in a XML subset of SyncML language.

OPC	
Full Name / Standard	Open Platform Communications Originally: Object Linking and Embedding (OLE) for Process Control
Specification-/ Standardisation-Body / Patents	OPC Foundation
Summary / Short profile	OPC is a standard that is commonly used to connect monitoring and process control devices from different manufactures in real-time. Hereby it serves as a bridge between diverging technologies and enables them to communicate transparently through so called OPC Objects. Once a hardware manufacturer implements an OPC server it is ensured, that this device will be able to communicate with any other hard and software that adheres to the specifications. For example a SCADA (Supervisory Control And Data Acquisition) system for which an OPC client is available can now access the data provided by the OPC server. This approach greatly reduces the effort required to provide interoperability, as once servers and clients are implemented they can be reused in any combination to satisfy the needs. There are no limitations on what information can be provided through OPC. OPC is primarily based on the Microsoft technologies Distributed Component Object Model (DCOM), OLE and Component Object Model (COM). Therefore Windows is the basis of OPC. However the newer Standard OPC Unified Architecture removes this limitation. Security: - Authentication via X.509 - Message integrity

Open Smart Grid Protocol (OSGP)	
Full Name / Standard	Open Smart Grid Protocol (OSGP)

Specification-/ Standardisation-Body/ Patents	ETSI GS OSG 001
Summary / Short profile	The Open Smart Grid Protocol (OSGP) is a family of specifications published by the European Telecommunications Standards Institute (ETSI) used in conjunction with the ISO/IEC 14908 control networking standard for smart grid applications. OSGP is optimized to provide reliable and efficient delivery of command and control information for smart meters, direct load control modules, solar panels, gateways and other smart grid devices. With over 3.5 million OSGP based smart meters and devices deployed worldwide it is one of the most widely used smart meter and smart grid device networking standards. ETSI GS OSG 001 provides a table-oriented data storage and command system, which provides for not only smart meters and related data but for general purpose extension to other smart grid devices. OSGP is designed to be very bandwidth efficient, enabling it to offer high performance and low cost using bandwidth constrained media like PLC.

SafetyBUS p	
Full Name / Standard	SafetyBUS p
Specification-/ Standardization-Body/ Patents	Safety Network International e. V.
Summary / Short profile	SafetyBUS p is based on the CAN bus and is designed to provide safe fieldbus communication between safety directed applications, mainly targeting factory automation. In addition to the layer 1 and 2 definitions inherited by the CAN bus, SafetyBUS p defines mechanisms for safety on layers 2 to 7. The safety mechanisms used are: - Sequential numbering - Watchdog - Echo - Sender and receiver ID - CRC checksum SafetyBUS p is approved to category 4 after EN954-1, EN 60204, EN IEC 62061, according to TÜV after AK 6 DIN V 19250, SIL 3 after EN IEC 61508 and NFPA 79.

	SafetyBUS p focus on timely delivery and data integrity makes it suitable for the application in safety centric environments.

TTCAN	
Full Name / Standard	TTCAN (time-triggered CAN)
Specification-/ Standardisation-Body/ Patents	ISO 11898-4
Summary / Short profile	The TTCAN (time-triggered CAN) protocol (standardized in ISO 11898-4) is a higher layer protocol on top of the CAN (Controller Area Network) data link layer as specified in ISO 11898-1. It may use standardized CAN physical layers such as specified in ISO 11898-2 (high-speed transceiver) or in ISO 11898-3 (fault-tolerant low-speed transceiver). It is applicable to setting up a time-triggered interchange of digital information between electronic control units (ECU) of road vehicles equipped with CAN, and specifies the frame synchronization entity that coordinates the operation of both logical link and media access controls in accordance with ISO 11898-1, to provide the time-triggered communication schedule.

UDP	
Full Name / Standard	User Datagram Protocol
Specification-/ Standardization-Body/ Patents	IETF (specified in RFC 768)
Summary / Short profile	UDP is a simple transport protocol which provides means to send datagrams from one application to another, i.e. it basically enables IP packets to be send from port to port on source/destinations. This leaves no guarantee whatsoever for the messages to arrive, however, packets are not exposed to any retransmission schemes hence it is usually also faster, if data is kept small. Unlike standard TCP, UDP allows broadcast and multicast to a number of devices within the same sub-network as it effectively can utilize the lower layer's broadcast mechanisms. It also offers no increased reliability or congestion control.

ANNEX: MARKET READINESS SURVEY QUESTIONNAIRE

1. *Name of the participant:*

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2. *Position in the company:*

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3. *Name of the system:*

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4. *Website for the system:*

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5. *EV charging mode:*

Charging mode	*Yes/No*
Static plug-in	
Conductive dynamic	
Inductive static *(slow or fast charging while EV is parked)*	
Inductive stationary *(fast charging during very short stops)*	
Inductive dynamic *(fast charging while EV travels)*	

6. *Current Technology Readiness Level for system as a whole (1 to 10 please see p.6)*

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7. *Technology Readiness Level for system as a whole after 12 months (1 to 10)*

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8. Current Manufacturing Readiness Level for the system as a whole (1 to 10 please see p.7)

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9. Manufacturing Readiness Level for the system as a whole after 12 months

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10. Current Technology and Manufacturing readiness levels for components

Module	**TRL**	**MRL**
Power Transmission		
Power Reception		
Communication		
Comments on any specific barriers or specific components (e.g. Coils / litz wire, Power electronics, switching technology, foreign object detection technology, etc….):		

11. Technology and Manufacturing readiness levels for components after 12 months

Module	**TRL**	**MRL**
Power Transmission		
Power Reception		
Communication		
Comments on any specific barriers or specific components (e.g. Coils / litz wire, Power electronics, switching technology, foreign object detection technology, etc.…):		