Fast Inductive Charging: The General Concept, the Definition of the Energy Needs and the Energy Management System

I. Karakitsios, E. L. Karfopoulos, *Member, IEEE* and N. Hatziargyriou, *Fellow, IEEE*

***Abstract* — The limited range anxiety, is one of the main obstacles in the vast deployment of electric vehicles. Fast inductive charging can effectively address such issues, enabling drivers to charge their electric vehicle's battery in a wireless way within a small amount of time. Particularly, on-route inductive charging offers the ability to charge while moving eliminating further concern on the travel range of an electric vehicle. The FastInCharge project will develop innovative fast inductive charging solutions for electric vehicles, concerning both static and on-route inductive charging designs. The FastInCharge project will also identify the energy needs of inductive charging, while an energy management system will also be developed aiming to balance the EV users' energy needs and the existing network capacity limitations.**

***Index Terms*—Electric Vehicles, Inductive Charging.**

I. Introduction

Lower emissions of greenhouse gases and other air pollutants demand significant changes in the transportation factor. Electric vehicles have been identified as a cornerstone of emission control strategies by many governments around the world. However one of the main obstacles for the mass deployment of electric vehicles is their rather limited travel range as well as the relatively high price of their battery. Fast charging could effectively deal with such issues, offering the drivers the ability to charge their vehicle at a really small amount of time. Inductive charging is a particular fast charging solution which can further simplify the process of charging. The need for any physical connection between the EV and the station is eliminated, while issues involved with the use of wire, like potential hazards due to electrocution or precautious measures to deal with harsh environments (like rain or snow), can easily be avoided.

Furthermore, on-route inductive charging can eliminate any concerns connected with the limited travel range of the vehicles. A huge battery is no longer required in order for the vehicle to perform a long range trip, since it can easily receive energy from on-route stations while moving on the road. Hence the battery size, and therefore the final price of the battery, could be significantly decreased.

The general concept of inductive charging is depicted in Fig. 1. The AC voltage provided from the grid is rectified to a DC voltage in order to be provided to a DC/AC high frequency inverter. Such an inverter provides a high frequency current to the charging coil, which is necessary to transfer sufficiently high power to the vehicle. The high frequency current of the charging coil causes a magnetic flux to pass through the surface of the secondary charging coil, or else the "pick-up" coil, installed in the vehicle. The magnetic flux passing through the pick-up coil induces an AC voltage, which is then rectified in order to be offered to the vehicle's battery. Compensation capacitances are necessary both in the primary and secondary side, in order to improve the power delivered to the vehicle as well as the efficiency of the whole system.

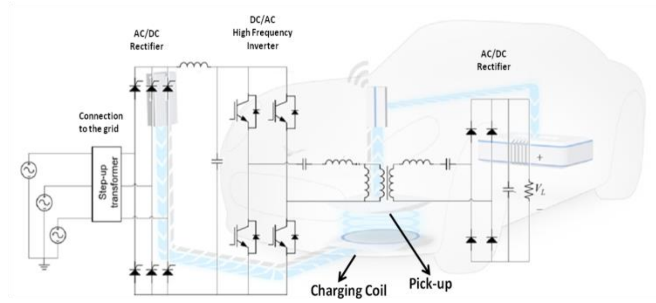


Fig. 1 General concept of Inductive Charging

Magnetic couplers on static inductive charging stations can either incorporate ferrite cores in their design or not. Although some designs without the use of ferrite have been proposed [1], ferrite tends to be necessary in the design of an inductive power transfer system in order to reinforce the magnetic flux passing through the surface of the pick-up [2]. Indicative examples of such designs involve a solenoid coil wrapped around a ferrite plate [3]. Despite the effort for the improvement of similar designs [4], magnetic losses can be significantly high in such systems, while concerns are also raised regarding the suppressions of the field leakage [5]. On the other hand circular pads, comprising a circular coil placed above a ferrite layer, can effectively deal with such issues. Improvements to the circular pad have also been proposed [6], yet it is proven that such systems cannot provide high power in case of a large air gap, while their tolerance in horizontal misalignment is quite low. Trying to eliminate such concerns, the University of Auckland has proposed a different kind of design, called the Double-D or DD pad [5], [7]. This particular pad enables the transfer of a greater amount of power compared to circular pads, while it is also more tolerant to lateral misalignment [7]. The DDQ pad and the bipolar pad, also developed by the University of Auckland, are

The authors are with the National Technical University of Athens, Athens, 15773, Greece (e-mail: ekarfopoulos@gmail.com; babismarmaras@gmail.com; nh@power.ece.ntua.gr).

improvements to the DD pad, further increasing the tolerance to misalignment [7], [8].

Regarding on-route inductive charging, two main kind of magnetic couplers exist. The first kind consists of a long track which is called after the shape of the track it comprises. Examples involve the E-type, the U-type and the W-type coupler [9]. A novel inductive power transfer system, named I-type, is proposed in [10], incorporating a narrow width track. This particular design is able to transfer a great amount of power, while reducing the emitted magnetic field. The second kind of on-route inductive charging system incorporates the use of many “segments” [5], [11], [12], with a design similar to that used in static inductive charging. The operation of each pad may be the responsibility of separate converters, yet such a design could lead to unaffordable economic costs. Novel techniques to drive two [11] or even more pads [12] have been proposed.

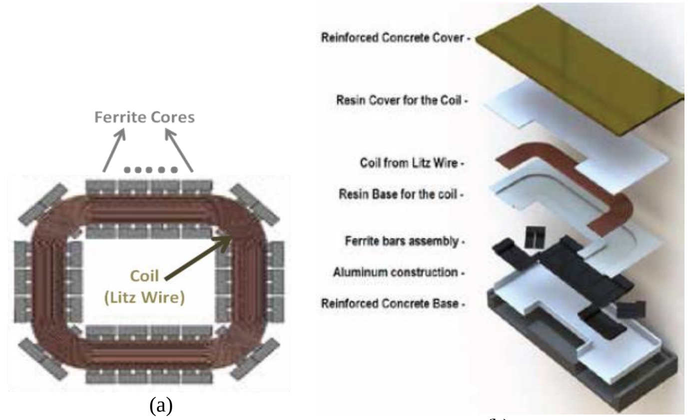
The FastInCharge project [13] aims to develop innovative fast inductive charging solutions for electric vehicles, concerning both static and on-route inductive charging designs. The FastInCharge project’s scope is to foster the democratization of electric vehicles in the urban environment by developing an easier and more comfortable charging solution. This solution will enable to ease the use of Electric Vehicle (EV) by the large public and facilitate their implementation in the urban grid. FastInCharge’s intention is to develop a cost-effective modular infrastructure offering a global solution for EV charging, while its success will boost research in the direction of dynamic charging solutions.

In this scope, FastInCharge introduces a novel integrated wireless charging infrastructure in order to address consumers’ acceptance of electric vehicles by getting rid of the autonomy issue. The proposedinfrastructure will be implemented within a real road environment in Douai, France. Furthermore, an energy management system will be developed in order to optimize the energy delivery to the stations and its interaction with the grid and vehicles. The impact of the infrastructure’s integration in the urban environment will also be studied in order to foresee eventual problems that would occur in the frame of a real integration.

In Section II the concept introduced in FastInCharge will be presented. Section III concerns the energy needs of the static fast inductive charging demand, while Section IV explains the energy management system that will be developed in the scope of FastInCharge.

II. FastInCharge Concept

The magnetic coupler proposed in the FastInCharge project is a rectangular shaped pad (Fig. 2), with a mass of 28kg and dimensions 700mm X 800mm X 90mm. The frequency of the converter lies between 12 and 20 kHz, while the SS compensation network is incorporated in the design [14]. In order for the system to be compliant with the ICNIRP 2010 guidelines for exposure of the general public to EM fields [15], aluminum shielding is used in the design [14] to reduce the emitted EM field.



(b)

Fig. 2 (a) Design presented in the FastInCharge project, (b) 3D section view of the primary coil [14]

An air gap of 70-90mm between the two coils is achieved, while the tolerance to horizontal misalignment reaches ±150 mm. The system has a nominal input power of 30kVA, with an efficiency of up to 92% [16]. Since the efficiency of the whole system highly depends on the air gap a mechanical system (Fig. 3) will be developed within the scope of the project in order to ensure that the gap between the two coils remains at the appropriate values. In order to account for the horizontal misalignment visual marks will be incorporated in the design of the stations in order to assist the drivers, while driving or parking their vehicle.

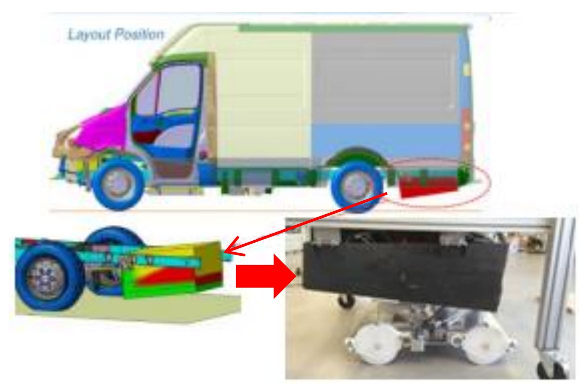
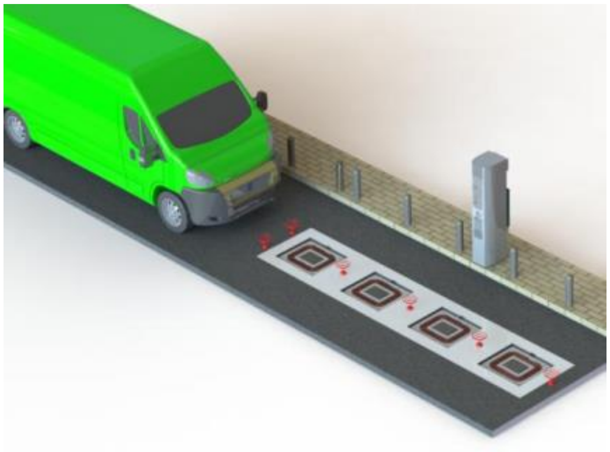
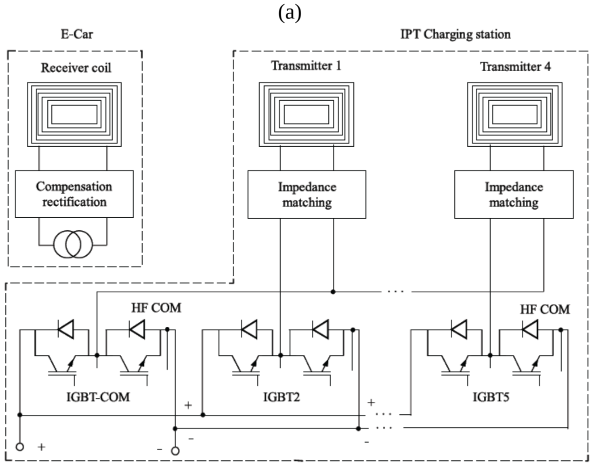


Fig. 3 Mechanical system aligning the gap between the primary and the secondary coil

The on-route stations will comprise four primary coils (Fig. 4a). The relevant power converter incorporated in an on-route station is illustrated in Fig. 4b. The converter topology consists of one common IGBT module and four IGBT modules, one for each one of the four primary coils [16]. The common IGBT module works in a continuous operation mode, and only one of the other four modules is enabled to form a full bridge converter with the common module [16]. Although such a design limits the operation of the system so that only one primary coil is powered every time, the economic cost can be considerably decreased.



(a)



(b)

Fig. 4 (a) Implementation of the FastInCharge concept in an on-route application, (b) Power converter topology for an on-route inductive charging station [16]

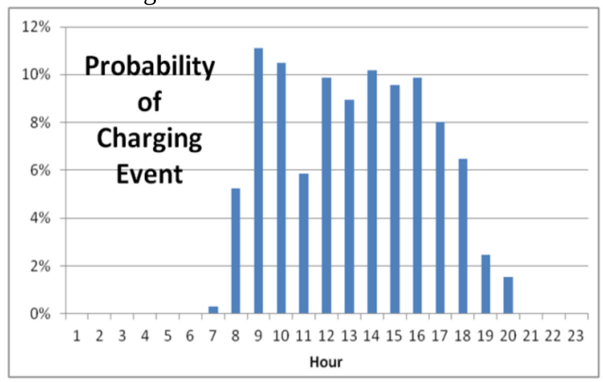
III. Defining The Energy Demands of Static Inductive Charging

Tools defining the demand of EVs concerning conductive charging stations have already been developed taking into account both stochastic (arrival time at home, daily travel distance, number of vehicles charging at each power level) and deterministic (total number of EVs, type of electric vehicle ,i.e. L7e - M1 - N1 - N2, battery consumption of each class) parameters [17]. Fast inductive charging, however, is considered as emergency charging: EV drivers demand immediate quick charging to regenerate their battery in order to reach their destination.

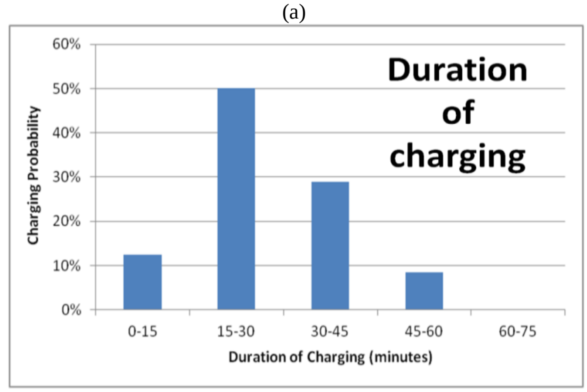
Two additional stochastic parameters are therefore essential for the definition of inductive charging energy needs:

i. The probability of a vehicle to enter a static inductive charging station during the day, and
ii. The duration of each charging session

Inductive charging is a technology developed in very recent years, so there is no operational background concerning its demand profile. However, the demand profile of stationary fast stationary inductive charging will be similar to conventional fast conductive charging. After processing real data on fast conductive charging stations, the probability of a vehicle entering a charging station at a particular hour of the day, as well as the duration of a charging event are defined. As depicted in Fig. 5a, all of the charging sessions are expected to occur between 7am and 9pm, while the traffic is increased in the morning (8.00-10.00) and the middle-day hours (12.00-18.00). Concerning the duration of each charging event (Fig. 5b), most of the charging events last for 15-30 minutes, a significant amount of them lasts for 30-45 minutes, while none has a duration longer than one hour.



(a)



(b)

Fig. 5 (a) Charging events occurring during the day, (b) Amount of time the vehicles remain on the stations

In order to examine the impact of fast inductive charging on the EV demand a number of study cases were examined, while considering both conventional conductive and fast inductive charging. Initially, 1000 electric vehicles are considered to charge only at home at conventional conductive charging stations. Conductive charging is expected to occur at Level 1 (3.6kW) and Level 2 (11kW) at the late evening and night hours, as soon as the drivers have performed the last trip of the day. In this case, a significant peak of 2.67MW in the EV demand can be observed in the evening hours (Fig. 6). When considering fast inductive charging, it is assumed that 10% of the EV fleet relies on fast inductive charging solutions. This EV fleet percentage is not expected to charge at home conductive charging stations, either because the energy received from fast inductive charging stations is enough to cover their daily energy needs, or simply because they missed to charge their vehicle the night before. In this case the EV demand during the evening is decreased (2.45 MW), while an increase can also be observed in the morning and middle-day EV demand. In case of a mass deployment of fast inductive charging stations, the percentage of the drivers daily relying on fast inductive charging solutions could be as high as 30%. In this scenario the peak in the evening demand is decreased to

1.91MW, while a significant increase of more than 0,6MW in the morning demand can also be observed.

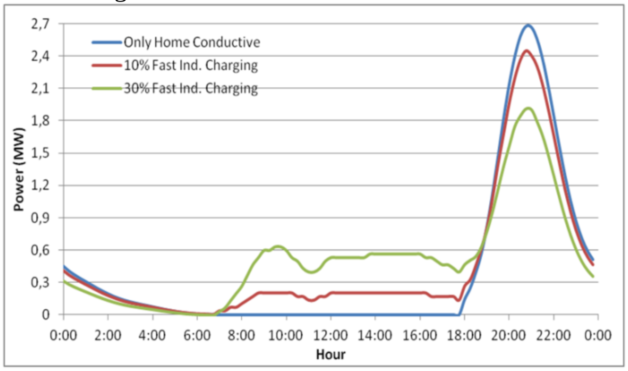


Fig. 6 EV demand in case 10% or 30% of the EV users rely on fast inductive charging solutions.

In the study cases examined before the drivers charging their vehicle on fast inductive chargers during the day, are not considered to charge their EV when they return home. However, increased energy needs could lead the drivers to use both fast inductive and home conductive solutions during the day. For instance, some of the drivers may charge their car during a day on a fast inductive charging station, and return home with quite a low state of charge, requiring to plug-in their vehicle. Therefore, a scenario is considered, where 30% of the EV users use fast inductive charging stations, while also receiving a percentage k of their daily energy needs from home conductive charging. This percentage could be as high as 50% of a vehicle's daily energy requirements (in case the driver has charged their vehicle during the middle of the day at a fast inductive charging station and has already covered half of the average daily distance until they return home) or even be equal to zero (in case the drivers having already charged at fast inductive chargers during the day, might forget to plug in their vehicle when they return home, not requiring any additional energy). It is evident in Fig. 7 that for any percentage k the middle-day and morning fast inductive charging demand is the same. However, in the case where the drivers using fast inductive charging solutions also cover half of their daily energy demand from home conductive charging stations (i.e. k=50%) a peak of 2.38MW can be observed in the late evening demand. Even in this situation, however, fast inductive charging is able to shift a significant amount of the EV demand away from the evening, towards the middle-day and morning hours.

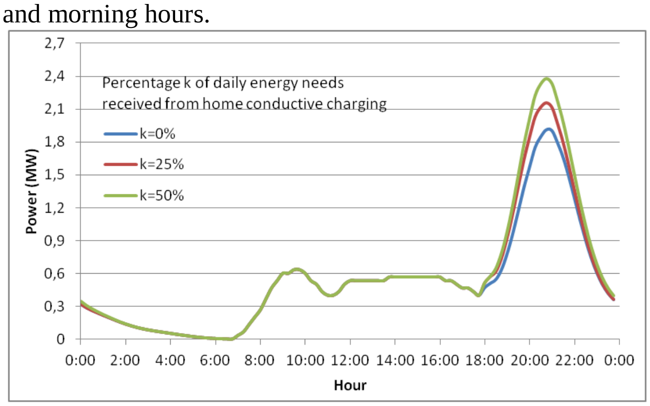


Fig. 7 EV demand for different cases of the percentage k received from home conductive charging

IV. Energy Management System

As the number of installed inductive chargers in the grid increases, the load profile of the network will be significantly modified, due to the high charging power (approximately 30kW) served from this type of chargers. The additional charging demand may provoke grid issues such as voltage excursions, network overloading etc. Consequently, an Energy Management System is necessary in order to mitigate potential disturbances in the normal operation of the grid.

Inductive charging technologies offer EV owners the option of fast charging probably in a correspondingly increased energy tariff compared to the conventional conductive chargers of Level 1and 2. EV owners will possibly be willing to pay more only in case of emergency charging, for instance in order to be able to continue their travel. In other words, inductive charging should be considered as a service of "charge as fast as possible". Since, there is no time flexibility in case of inductive charging, the availability of each inductive charging infrastructure should be defined based on social and technical criteria in order to meet EV owners needs without provoking any network operational disturbance.

The scope of the Energy Management System is to make EV owners aware of the availability of each inductive charging spot that can serve them without causing any network operational issue. A user interface will be developed so as to inform EV drivers for the location of the available inductive charging spots. The user interface will be an applet that can be installed in a tablet or a mobile phone. Furthermore, the user interface will provide an estimation of the remaining time that unavailable inductive charging spots will remain busy. Based on this information and according to the EV driver's travel needs (i.e. direction and energy requirements), the driver will be able to decide to which one of the dispersed available inductive chargers will drive on. Finally, EV drivers will be able to book a specific inductive charging spot and communicate their estimated charging time.

The energy management system architecture is presented in Fig. 8. Three main modules can be distinguished in the energy management system: the ***user awareness module***, which makes EV drivers aware of the available charging stations, the exact location of each station as well as the electricity cost, the ***monitoring module***, which is responsible for the interaction between the charging station and the energy management system and the ***decision module***, which is responsible for interacting with the wholesale market for the procurement of the required energy, while also serving the charging/booking request of EV owners.

Furthermore, an applet will be developed which will depict the locations of the existing fast inductive charging infrastructures, the availability of each station, as well as the time that busy charging posts will become available again. The drivers can, therefore reach a convenient charging station according to their desired driving plan. The EV owners will also be offered the ability to book a specific station for a desired amount of time, according to a pricing policy (multi-tariff pricing), developed in such a way so as to provide the necessary incentives to promote charging during off-peak hours.

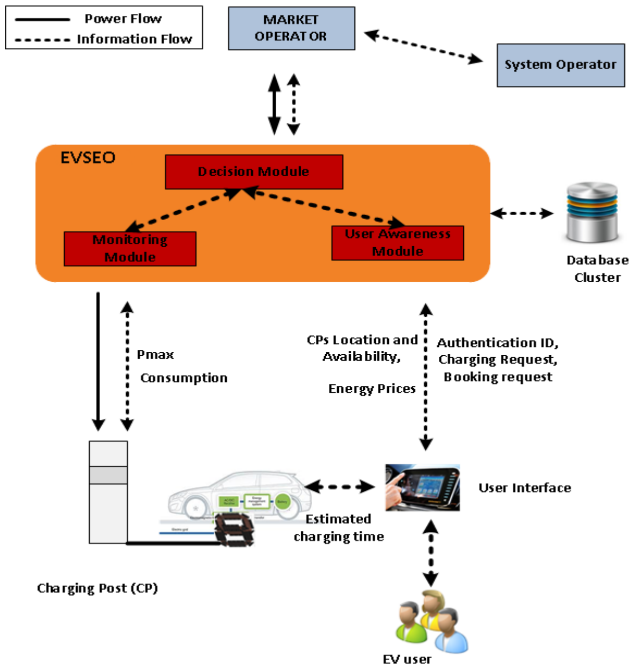


Fig. 8 Overall outline of the energy management system

V. Conclusions

Fast inductive charging is a newly developed technology that will offer the driver to wirelessly charge their vehicle in a really small amount of time. The FastInCharge project will develop a highly performing inductive charging solution taking into account both static and on-route inductive charging stations. In this paper the concept of the FastInCharge project was presented, while the energy needs of inductive charging were also identified. Results suggest that inductive charging introduces an EV demand during the middle-day and morning hours, while reducing the energy needs in the evening hours.

An increment in static and on-route inductive charging stations is expected to introduce quite a high charging demand, which could lead to serious grid issues. The energy management system that will deal with such issues was also presented. The energy management system developed in the scope of the FastInCharge project will give the driver the ability to choose between a number of available chargers, or even book a charger they wish to use a couple of hours ahead, while preventing any grid violation that might occur.

VI. Acknowledgment

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