Energy Management System for fast inductive charging network: The FastInCharge project

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***Abstract* — One of the major concerns for the mass roll-out of electric vehicles is the driving range anxiety and the battery charging duration. The FastInCharge (FiC) project aims to introduce an integrated inductive charging solution which enables Electric Vehicle (EV) users to charge their battery wirelessly within a short time period. Static and on-route charging technologies are developed and demonstrated within FiC project offering charging capabilities during both EV commuting and non-commuting periods. As the fast inductive charging network becomes larger, the load profile of the network may be significantly modified, due to the increased nominal power (approximately 30kW) of such charging technologies. This additional charging demand may provoke grid issues such as voltage excursions, network overloading etc. Consequently, an Energy Management System is necessary for mitigating the potential disturbances in the normal operation of the grid. This paper presents the energy management system developed within the FiC project facilitating the fast inductive charging of EV while the network operation remains stable.**

***Index Terms*—Electric vehicles, inductive charging, energy management, web services.**

I. Introduction

The European Union has set the overall goals of reducing the number of urban vehicles functioning with conventional petrol by 50 % before 2030, and excluding totally such vehicles from cities by 2050. However, the driving range autonomy and the charging duration are the major factors impeding the mass roll out of electric vehicles (EV) in the market sales. Fast charging infrastructures [1]-[10] are the most promising solution towards this direction since they enable a complete EV battery charging within a short time period, offering maximum travel distance for the next trip. Inductive charging technology is a particular fast charging alternative which enables high power exchange between the grid and the EV battery in a contactless way.

From the end-users perspective, fast inductive charging technologies can considerably reduce their e-mobility concerns. However, the integration of fast inductive chargers into power systems may raise new grid operational challenges to the system operators. These stations enable the exchange of high power quantities (>30kW) with the electrical grid resulting in a significant network load profile modification.

Generally, EVs can be regarded as a new type of distributed energy resources which are characterized by their mobility. Mobility means that EVs are able to connect at different parts of the grid and still enjoy the same quality of services. The energy requirements that fulfill EV needs are highly dependent on the EV owners' traffic pattern. The charging demand of an EV fleet can be synchronized with high consumption periods resulting in high peak demand which can strike the network operation, i.e. severe feeder voltage excursions and equipment overloads [11]-[12]. Consequently, in order to prevent network operational issues, EV charging management schemes should be implemented.

This paper aims to present the EV charging management system developed within the framework of the FastInCharge project[1]. The aim of the energy management system is to facilitate EV charging in an urban environment offering fast wireless charging capabilities to EV users while considering the network capacity limitation.

Section II presents briefly the FiC concept. Section III analyses the general concept of the energy management system developed for the scope of FiC project. The core application is analyzed in Section IV. The user interface enabling the interaction between the EV user and the energy management system is described in Section V. The paper concludes in Section VI.

II. FastInCharge Concept

The FastInCharge project aims at fostering the democratization of electric vehicles in the urban environment by developing an easier and more comfortable charging solution which will enable to ease the Electric Vehicles (EV) use by the large public and facilitate their implementation in the urban grid. In this scope, a complete charging infrastructure will be developed and demonstrated in order to:

1. *Address consumers' acceptance of electric vehicles by getting rid of the autonomy issue,*

2. Test its implementation and assess its easy feasibility,

3. Optimize the energy delivery to stations and its interaction with the grid and vehicles,

4. Study the impact of its integration in the urban environment to foresee eventual problems that would occur in the frame of a real integration.

The project's intention is to develop a cost-effective modular infrastructure offering a global solution for EV charging. Its success will boost research in the direction of dynamic charging solutions. The overall view of the components and interfaces of the FiC charging approach is presented in Fig. 1. The black lines indicate the energy flow,

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while the red ones indicate the information exchange. The continuous, red line boxes indicate the services offered by the FiC platform.

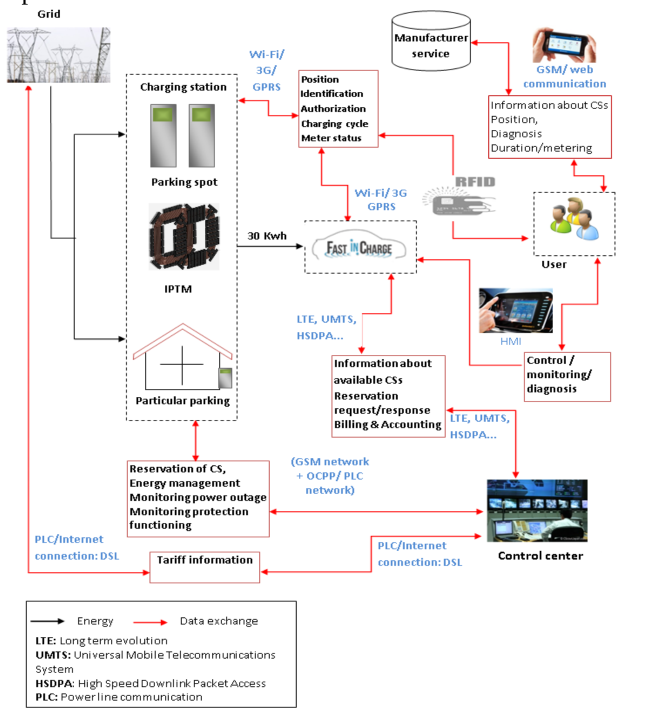


Fig.1 Overall view of the components and interfaces in the FiC project

Inductive chargers can be discriminated into two main categories:

- ✓ *The **static charging stations**, where the electric vehicle charges during non-commuting hours.*
- ✓ *The **on-route charging stations**, where the vehicle receives power while moving on the road.*

A. Static charging stations

Fig. 2 illustrates the schematic diagram of a static fast inductive charging infrastructure.

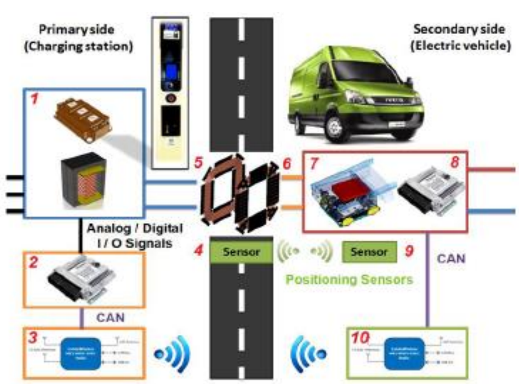


Fig. 2 Schematic diagram of the FiC static charging station [10]

The primary side is the charging station where the power electronics interfaces and safety devices (elements #1) are located producing a high frequency current to the primary underground coils (element 5). The secondary coil (element #6) is placed at the bottom of the car inside a mechanical moving system (element #7) which aligns the gap between the primary and the secondary coil. The battery management system (element #8) is responsible for the charging/ discharging operation of the EV battery. The charging process is controlled by a closed loop (elements #2, #3 and #10) which enables the wireless information exchange between the battery management system and the charging station. Finally a sensors system (elements #4 and #9) is implemented recognizing the presence of an EV over the primary coil which is afterwards electrified.

B. On-route charging stations

One the core innovative steps of this project is the on-route wireless charging of an electric vehicle. The dynamic charging approach enables the EV battery charging while the EV moves on the road without the need of being parked. This approach is illustrated in Fig. 3. The dynamic wireless charging infrastructure comprises four primary coils placed successively on the road. As soon as the EV reaches the on-route charging station, the first primary coil is electrified allowing the energy transfer to the EV battery as it moves longwise the primary coil. Afterwards, when the EV leaves the first primary coil, this is switched off while the second one is electrified.

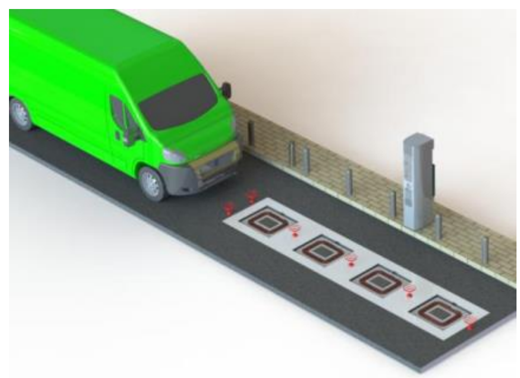


Fig. 3 Schematic diagram of the FiC on-route charging station [10]

III. ENERGY MANAGEMENT SYSTEM

The proposed energy management system considers both the EV drivers needs as well as the constraints that are set by the capacity of the existing grid infrastructure.

The energy management system should fulfill the following objectives:

a. ***Monitoring the operation of the charging stations***: The energy management system should allow the operator of the charging stations to monitor the consumption of the charging stations in real-time not only for billing purposes but also for identifying the demand flexibility that can be offered to support network operation.
b. ***Enable the remote control of the maximum charging rate of the stations under emergency network operational conditions***: In case that the network operation is close to its capacity limits (equipment overloading) due to the increased demand of the fast inductive charging stations, the energy management system should enable the remote control of the maximum charging rate of the stations located at the specific part of the grid where the operational issue lies.

c. ***User awareness of the location, the availability and the electricity cost of the fast inductive charging stations***: The energy management system should make EV drivers aware of the locations of the existing fast inductive charging infrastructures in order to be able to decide the most convenient place for charging their electric vehicle in respect to their trip destination. Moreover, the energy management system should inform EV drivers about the availability of the charging stations which might be free, when no EV is charging at the stations, or not available, when an EV is charging at the station or a network operational issue exists. Finally, a pricing policy (multi-tariff pricing) should be adopted in order to incentivize charging during off-peak hours.

d. ***Offer booking services to EV owners*** enabling them to book the most suitable charging station at the most convenient time, considering their trip destination as well as the electricity energy prices: The energy management system should allow EV drivers to book the future use of a fast inductive charging station which is the most convenient one taking into account the travel plan, the energy mobility needs and the electricity prices.

The energy management system architecture is presented in Fig. 4. The interactions among the FiC actors are plotted with dashed lines while the power flow paths are shown with continuous line. The energy management system comprises three components: the user awareness module, the monitoring module and the decision module.

When an EV owner needs to charge its EV battery, he/she will drive to the nearest available charging post. However, the closest fast inductive charger might be occupied and, consequently, the EV owner will have to find the next closest charging point. For this reason, the user awareness module makes EV owners aware of the available CP as well as the estimated remaining time that busy CP will become available again. Therefore, based on their charging needs, their travel direction as well as the location of available charging stations, EV drivers can reschedule their driving route to the desired destination in order to reach the most convenient and available charging station.

The monitoring module is responsible for the interaction between the charging station and the energy management system. It is responsible for communicating with the metering infrastructure of the charging station and gathering the data concerning the energy consumption. Moreover, the monitoring module is responsible for remotely controlling the maximum allowable charging rate of all the charging stations. The actual charging rate is defined by the battery management system of the electric vehicle which cannot be higher than the one defined by the energy management system.

The decision module is responsible for purchasing energy from the wholesale market and supply the charging demand of EV drivers. EV owners will be charged for the energy price at constant rates in order to prevent their exposure to high market energy prices during peak hours. Different pricing policies may be adopted either simple ones (i.e. multi-tariff) or advanced (dynamic pricing). Irrespectively of the adopted pricing mechanism, the energy price level is an indirect factor that affects the EV owner's charging time decision. Furthermore, the decision module is responsible for processing any charging or booking request of EV owners. Finally, the decision module offers demand response services to the market operator. In case of network operational issues (voltage excursions or network equipment overloading), the decision module can support the problematic grid area by reducing the charging rate of the charging stations located at that area up to 10%.

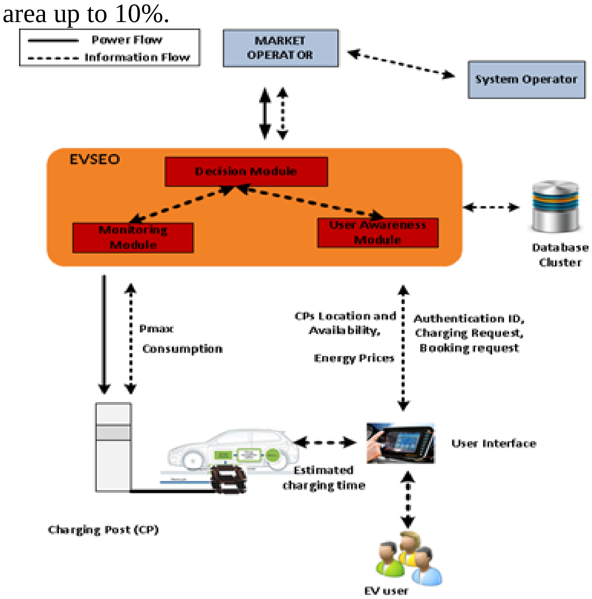


Fig. 4 The energy management system should balance EV drivers' needs and network operational constraints

IV. Core Application

The Energy Management System functionality (Core Application) was developed in Java 7 programming language with the help of Netbeans IDE (Integrated Development Environment). The core application's component diagram is presented via its component diagram in Fig. 5.

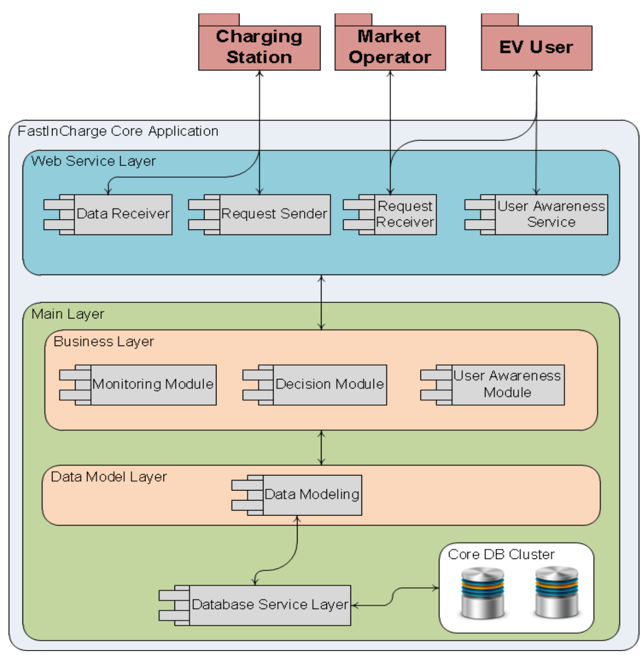


Fig.5 The core application's component diagram

The core application comprises two major layers namely the ***Main*** and the ***Web Service*** one. The intelligence of the core application lies in the Main layer where the charging/booking requests from EV users as well as the demand response requests for network support are processed. Furthermore, the Main Layer is responsible for the information management coming from the charging stations. The Web Service Layer enables the interaction and the information exchange between the external entities (i.e. charging station, EV users and market operator) and the energy management system modules.

A. Main Layer

This is further divided into two sub-layers namely the *business* and the *data model* one.

The data model of the Core Application was developed exploiting the Hibernate framework, an object-relational mapping library for the Java programming language.

For storing and managing all the requested data, a database was developed with the use of MySql RDBMS (relational database management system). The entity relationship diagram of the database is illustrated in Fig. 6.

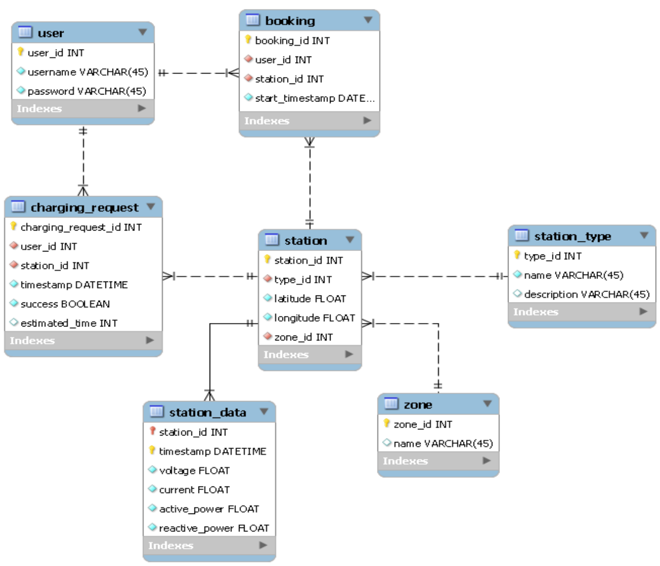


Fig. 6 The entity relationship diagram of the database

More specifically, the tables that were created are:

- *user*: defines the private data of EV users i.e. username and password
- *station*: defines the specifications of the charging stations, i.e. type, location data, and zone (defined by the electricity grid topology). The data stored in this table are considered static, ie with very low change frequency
- *station_type*: provides the type of every station connected to the grid. An inductive charging station can be either static or on-route.
- *station_data*: The data coming from the monitoring module are stored in this table, i.e. voltage, current, active/reactive power
- *zone*: includes the name of the zones that the charging stations belong to in respect to the network topology, for instance the name of a MV/LV transformer
- *booking*: contains all the successful booking requests received from the EV user
- *charging_request*: stores all the charging requests, successful or not of the EV users as soon as they have reached an inductive charging infrastructure, i.e. the user, the station, the time of request, the estimated charging duration and the validation of the charging request.

The Database Service Layer component is responsible for retrieving/storing data from/to the database and transforming the entity relationship data model described above to an object oriented one. The java classes of these objects constitute the Data Modeling component (Fig. 7).

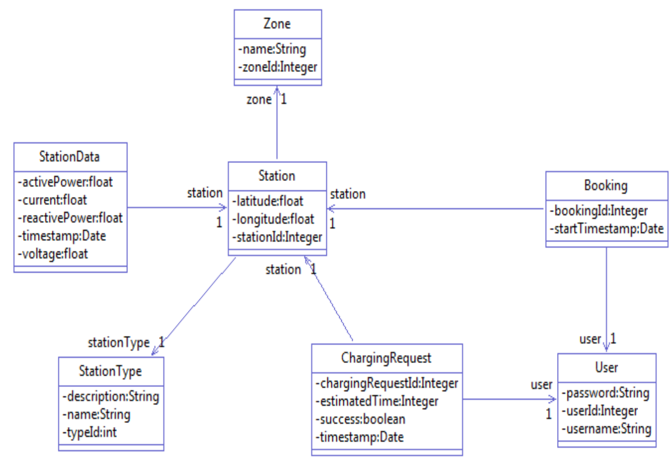


Fig. 7 The class diagram of data modeling component

Finally, the Business sub-layer contains all the intelligence of the core application. It comprises the monitoring module, the decision module and the user-awareness module components which are extensively analyzed in Section III.

B. Web Service Layer

The Web Service Layer is responsible for realizing communication between the external entities and the components of the business layer of the core application.

For the Web Service implementation both ***SOAP (Simple Object Access Protocol)*** and ***REST (Representational State Transfer)*** based Web Services can be adopted. Each web service technology has its own distinct features and shortcomings that make it more or less suitable for certain types of application [13]-[15]. REST-based web services present higher degree of flexibility and control, compared to SOAP ones, making them more suitable for mobile applications. In this respect, REST-based web services technology is adopted in the FiC application, published to a Tomcat server.

The Web Service is using Maven built framework in order to compile and link the project into a *.war* file and RESTEasy framework as a JAX-RS (Java API for RESTful Web Services) implementation which provides support in creating Web Services according to the REST architectural pattern. Service method results are sent to the client in XML(Extensible Markup Language) format, generated via JAXB (Java API for XML Binding) on the service.

The list of the developed functions of the web service is as follows:

Data receiver Component

- *sendMonitoringData accepts the operational data (voltage, current, power) of the charging stations.*

Request Receiver Component

- *sendBookingRequest* accepts/refuses a booking request at a given time from an EV user for a specific charging station depending on the charger's availability and the network operational conditions.
- *sendChargingRequest* accepts/refuses a charging request at the current timeslot from an EV user for a specific charging station depending on the charger's availability and the network operational conditions

Request Sender Component

- *sendDemandResponseRequest* accepts/refuses a demand response request for supporting the network operation under abnormal conditions. In case of acceptance, the consumption of the fast inductive charging stations located at the problematic grid area is curtailed by a specific percentage.

User Awareness Service Component:

- *userAuthenticate***:** Only authorized users can have access to the fast inductive charging network.
- *getStationData*: provides the location and the type of the charging station.
- *getCurrentStationsState* provides the detailed information for each charging station, i.e. current station state (free, busy and unavailable) and the estimated duration of the charging process.
- *getDailyStaionStates* provides the state and electricity price profile of a specific charging station for 24 hours ahead.

V. User Interface

A graphical user interface has been developed in order to facilitate the interaction between the user interface and the energy management system. Fig. 8 illustrates two snapshots of the user interface from a mobile device. Fig. 8a informs EV users about the location of the static and on-route inductive charging stations.

The different coloring of the charging stations indicates their current availability:

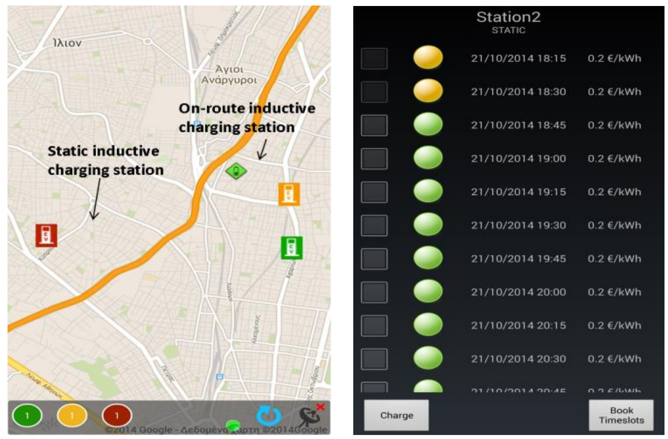
✓ *Green:* The station is available and the EV can charge as soon as it reaches the station

✓ *Orange:* The station is busy either because another EV is charging at that moment or the charging station is booked.

✓ *Red:* The station is not available either due to network operational issues or due to maintenance purposes.

Fig. 8b illustrates the detailed information that appears when tapping on a charging station icon. This screen allows EV users to request to charge their EV now or book future timeslot(s). Moreover, the electricity price for each timeslot is provided based on the tariff policy adopted by the energy management system.

The interface was developed using eclipse IDE with android ADT v.23.0.2.1259578 and the minimum android version supported by the project is 4.0 (API 14 – Ice Cream Sandwich). The geographic information is displayed using Google Maps. The communication with the Core Application is realized through calling the developed Web Service in an asynchronous way, such that each service request does not interfere with user actions in the User Interface.



(a) (b)

Fig. 8 The FiC user interface

VI. Conclusions

Fast inductive charging infrastructure is a premature technology which allows EV users to charge their EVs in a wireless way within a very short time-period (approximately less than 30 minutes). In this paper the concept of the FiC project and more specifically the energy management system was presented. The developed user interface enables the ease interaction of the EV user with the energy management system. The network operational benefits derived from the implementation of the proposed energy management system are currently evaluated and will be presented in a future research work.

VII. Acknowledgment

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