Information System Architecture for the Interaction of Electric Vehicles with the Power Grid

Business-case individual instantiation of a generic architecture allows for inter-operable information flows

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***Abstract*—The main challenge in all application areas of EV usage still is the energy storage within, as well as the energy transmission into an EV. However, this storage and transmission of energy also allow for synergies with a smart grid, if the information is adequately exchanged between roles in the energy and mobility sector. Since the energy transmission is a so called "fixed and intersection point" of E-Mobility, interoperability is required not only on an electrical (e.g. plugs), but also on an informational level. Standardization efforts are currently underway (e.g. IEC 15118), yet a comprehensive, consolidating view on the information system around energy transmission is missing. Therefore, this paper suggests a generic information system architecture for e-mobility (EM-ISA) derived from the Smart Grid Architecture Model (SGAM). EM-ISA shall be a base for companies to develop innovative services for their particular, ICT-enabled E-Mobility application area while at the same time stay at important points informational interoperable at the fixed and intersection point of energy transmission.**

Keywords—E-Mobility; Information System Architecture; EM-ISA; Electric Vehicle Communication; Smart Grid Architecture Model; SGAM; Fix and intersection point of E-Mobility

I. Introduction

As with most innovative technologies, electric propulsion for road vehicles has seen a significant hype. Recently, the hype has flattened and electric (road) vehicles (EV) have proved to be one of the main options towards a CO2-free and sustainable individual mobility. Certainly not the only [1], yet, the main challenge in all application areas of EV (e.g. delivery, taxi or car sharing services) stays energy storage within as well as energy transmission into an EV. Energy transmission is a (a) fixed and (b) intersection point of all application areas [2]. It is a fixed point (a), since every application needs to state how, where and when energy flows between an EV and the grid. It is an intersection point (b), since in most applications in addition to own decisions about charging infrastructure (at own parking space), an application relies on foreign decisions (at public parking space). Apparently, the configuration of both storage and transmission of energy are determined by the economic borders of the selected application. However, storage and transmission are not only an important cost factor of EV. They also allow for synergies with a smart grid based on energy from renewable resources. To unleash these synergies, mobility and grid needs must continuously be harmonized during EV usage. This harmonization requires significant information exchange between and within a variety of roles of the energy and mobility sector and especially with the EV user. Additionally to costs, the configuration of storage and transmission determines the "effort-range-ratio" of EV users, i.e. how much time and work is needed to get a certain range. In many applications, this ratio can be improved via high transparency about e.g. state of charge, availability of charging stations, smart grid tariffs, etc. The transparency is based on adequate information exchange and has to be configured for all applications at the fixed and intersection point. A generic information system architecture (ISA) can be the base for all application-specific configurations and therewith guarantees informational interoperability between a variety and of appearing business models [3].

The remainder of this paper is structured as follows. Section II shortly describes the state of art with respect to ISA in general as well as ISA for the domains smart grid and e-mobility. Moreover, this section identifies a lack of support for and then derives requirements to an ISA for E-Mobility (EM-ISA). Section III describes the proposed EM-ISA, before section IV will conclude and giving an outlook on future research in this area.

II. State of The Art in Information System Modelling for E-Mobility or Smart Grids

A. *Information System Architecture (ISA) in general*

An information system (IS) is a social and technical system that combines human and mechanical components to achieve the optimal allocation of information and communication [4], [5]. The description of such an information system is the base to design an adequate information flow within and throughout manifold business models. An information system can be detailed via an information system architecture (ISA). Several generic ISA have been proposed [5][6][7][8]. However, on the top upper level of these architectures, the architecture components are very similar and the architectures differ mainly with respect to their illustration. Although, the ISA concepts were originally developed for enterprises to describe and design their information system, it can be adapted to fit the needs for an information system around EV usage.

Enterprise architectures (EA) are more comprehensive than ISA, since they also include aspects not relevant from the information perspective (e.g. production abilities). However, EA are mainly used to bridge "…the gap between business and information technology (IT)." [9] Moreover, organizations and markets become more and more penetrated by information flows on all their levels of interaction and operation. For these two reasons, the distinction between EA and ISA is diminishing. Another concept, called (enterprise) architecture framework, does not only describe a domain (e.g. an enterprise), but gives additional support when using applying the architecture for a particular task.

B. *Domain specific ISA and frameworks for E-Mobility or Smart Grids*

Recently, more and more EA and architecture frameworks for the smart grid domain have been proposed, mainly driven by standardization bodies. In the USA, contributions come for example from the Grid Wise Council [10] and the NIST [11]. In Europe, the Smart Grid Coordination Group [12] has developed and is still improving the Smart Grid Architecture Model (SGAM). Although a final release is – at the time of writing – not yet public available, it is already now regularly used [12] and referenced [13] due to its completeness and comprehensibility. The SGAM distinguishes three dimensions [14]:

- Layers: business, function, information, communication, element
- Domains: (bulk) generation, transmission, distribution, distributed energy resource, customer premise
- Zones: field, process, station, operation, enterprise, market

These dimensions are put against each other therewith generating a space where each point in this space represents a certain perspective on the smart grid architecture. Each perspective can be detailed via own models and diagrams.

C. *Lack of support for creating solution ISA for the E-Mobility domain*

The established generic enterprise architecture models and frameworks are well adapted to design and develop information system of organizations. To some extent, they can even be used for inter-organizational information flows.[15] However, the fact that they are domain-unspecific makes it difficult to apply them in the prevailing domain-specific context such as e-mobility. An ISA distinguishing aspects such as infrastructure and mobile elements (EV and EV user) would eliminate this restriction.

The specific architecture models such as the SGAM are closer with respect to the E-Mobility domain. Yet, for two reasons it is not satisfying to simply apply SGAM as it is. At first, SGAM seems to be too weak with respect to the property of an IS describing also informational interaction between devices and humans. One reason is that the selected domain names (e.g. "customer premises") suggest a focus on things, henceforth neglecting the fact that people and their interaction with things are an important part of every IS. Another reason is that the level of (electrical) detail proposed (e.g. "field" and "process" within zones) is not needed in an IS and therewith increases complexity.

While these reasons are a question of interpretation and usability that could be slurred over, the most important aspect for coming up with a complementary ISA for E-Mobility is a lack of support for moving elements, in particular the EV. Yet, the SGAM is a very good base for to model an ISA around the e-mobility fix and intersection point of energy transmission.

D. *Requirements for EM-ISA*

The needed EM-ISA must conform to numerous requirements. They were identified from generic e-mobility use cases via a morphological box approach [16][17]. Most prominent requirements are:

- Domain specific → individual e-mobility at the fixed and intersection point of energy transmission. (R0)
- Supporting inter-organizational information flow → conformation with standards. (R1)
- Applicable in many countries → conformation with varying regulations. (R2)
- Configurable for organizations → derivation of individual solution ISA in correspondence with particular business models. (R3)
- Supporting user-interaction → consideration of both devices and users, as well as of its interface (HMI). (R4)

The Smart Grid Architecture Model (SGAM) has proved to be a good starting point to fulfilling already R1 (by the zone "market"), R2 (by its international agreement) and R3 (by their business model independence).

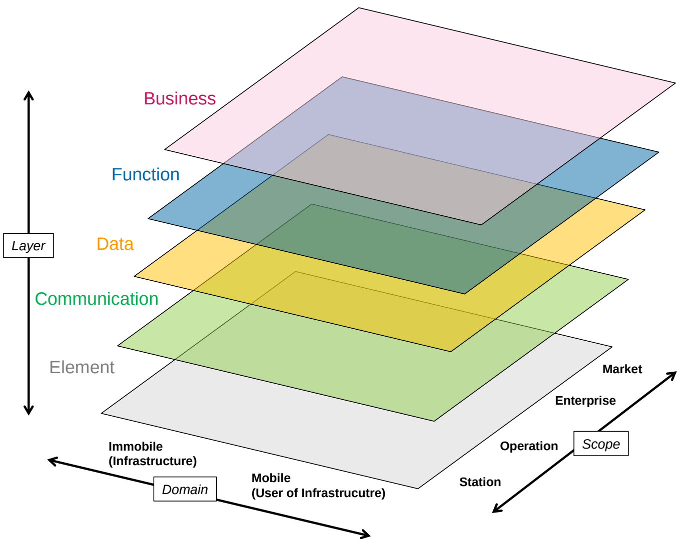

Figure 1. E-Mobility Information System Architecture (EM-ISA) Overview

III. Information System Architecture for E-Mobility (EM-ISA)

A. Overview E-Mobility ISA (EM-ISA)

EM-ISA uses the five layers of SGAM, adapts the domains and restricts the zones in order to correspond to the aim of modeling an information system around the energy transmission between EV and power grid. The resulting model is shown in figure 1 and is explained in the following.

While the business, function and communication layers stay unchanged, slight adaptions are necessary on the information and component layer:

- Information → Data = physical (e.g. hard disk) or logical data objects (e.g. data types). Motivation: The whole architecture is an information system. This layer in EM-ISA concerns only data that becomes information for the recipient if it is new (”informing”).
- Component → Element = physical objects or systems able to communicate (exchange data). Motivation: Component would not denominate well (EV) users, yet, the user is an integral part of an EM-ISA, interacting over an HMI with different devices (e.g. EV or EVSE).

Each layer contains objects (e.g. a function) that are linked together via one or more relation types (e.g. UML generalization). Furthermore, each layer has a relation with all other layers, yet, for a solution architecture, some relations can be more important than others. Despite all EM-ISA layers may contain physical as well as abstract representations (e.g. ISO/OSI-layers within the communication layer), the level of abstractness tends to increases bottom up (e.g. role models within the business layer exist independently of physical objects).

Since objects from other layers can be referenced in a layer, new objects are only created when they do not exist in any other layer. E.g. physical objects in a layer other than “element” are modeled only if they were non-communicating, since otherwise they would be already in the element layer.

The smart grid domains of SGAM are précised for e-mobility by the following clusters:

- Immobile: Objects related to infrastructure for users (charging and parking); representing electrically the power grid and the interface to the SGAM domains of generation, transmission and DER.
- Mobile: Objects related to users (EV and EV user) of infrastructure that typically appear at numerous and manifold infrastructure elements and types; corresponding electrically to customer (and its devices) in SGAM domains.

As in SGAM, the zones describe different levels of power management [14]. The EM-ISA widens this dimension and includes also the management parking and driving, since an IS for the energy transmission between grid and EV cannot be reasonably described without. Information is exchanged within and between these levels of management. The levels are organized hierarchically with respect to commitment, i.e. higher level decisions frame and – where necessary – overrule lower level decisions. In each zone of EM-ISA, different object and relation types can be modeled:

- Market: links particularly objects of type “person”, i.e. a legal person (enterprise or organization) or a natural person (human) via obligations (e.g. contracts) to one another. It represents the value chain (B2B and B2C) as well as the regulatory framework.

  Examples: regulation market, customer contracts
- Enterprise: describes the structure of one organization (e.g. processes) in order to reach its aims, i.e. fulfill obligations from the market level.

  Examples: EV innovation business unit, definition of charging bills.
- Operation: describes the control, planning and monitoring of physical objects and their relations (e.g. power flow). Actors are humans acting for themselves (private) or for an organization (business).

  Example: EV usage, EVSE management, charge control
- Station: describes the actual behavior of actors with actors being devices or human low-level task

  Examples: EV user starts charging, EVSE sends out charging event

The zones “field” and “process” are not considered in EM-ISA, since they are associated to a non-informational, rather technical level of management. As with SGAM and smart distribution systems,[13] security is also for the EM-ISA a cross-sectional subject that has to be considered on all layers. The same accounts for the interoperability respectively standards.

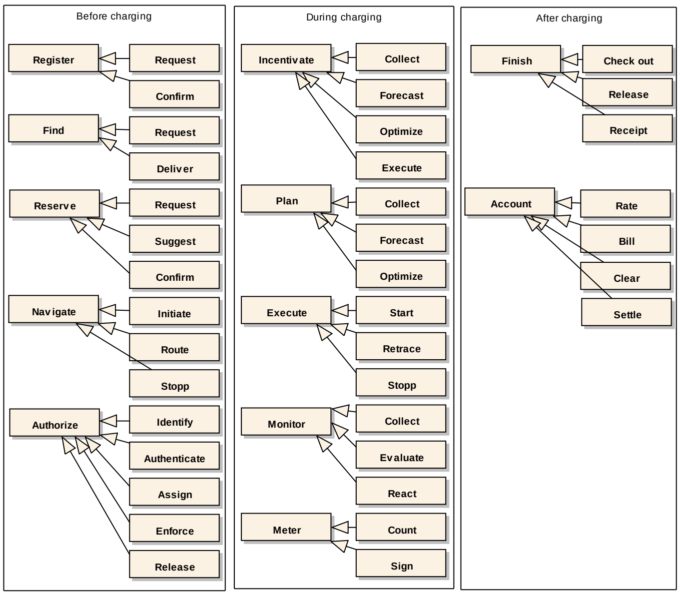

Figure 2. Function model of EM-ISA

B. *EM-ISA layers in detail*

EM-ISA is not to be intended only a framework, but additionally shall give orientation with respect to a certain point or area in this three-dimensional space. Therefore, diagrams in all layers precise reasonable options for a particular ISA (solution architecture). Subsequently, the layers are described in more detail.

On the business layer "… business cases which describe and justify a perceived business need" [14] are represented. Important object types are visions, roles, requirements, processes and use cases as well as corresponding relations types.

The main object type in the function layer is a function, or – due to the character of an IS more precisely – an ICT function. Figure 2 depicts the abstract representation of ICT functions needed around the energy transmission between grid and EV. These functions are structured hierarchically by UML generalization, as well as horizontally by a time-relation from an EV user's perspective on EV charging. The functions are to a large extent optional, e.g. accounting is not needed when there are no billed customers. In order to implement these ICT functions, domain specific as well as generic enablers as e.g. defined by projects of Future Internet (FI)-PPP program [18].

Within the data layer a variety of data object types and relation types are possible. Beyond physical data types with units such as "kWh", logical data types such as "identifiers" or "EVSE" need to be modeled.

The communication layer defines the means of information exchange between elements using data objects and supporting ICT functions. Beyond communication lines, protocols can be described in detail or being referred to. An example would be to model the upper level of communication line types relevant for EV and EVSE, such as cellular networks or near field communication (as used in figure 3).

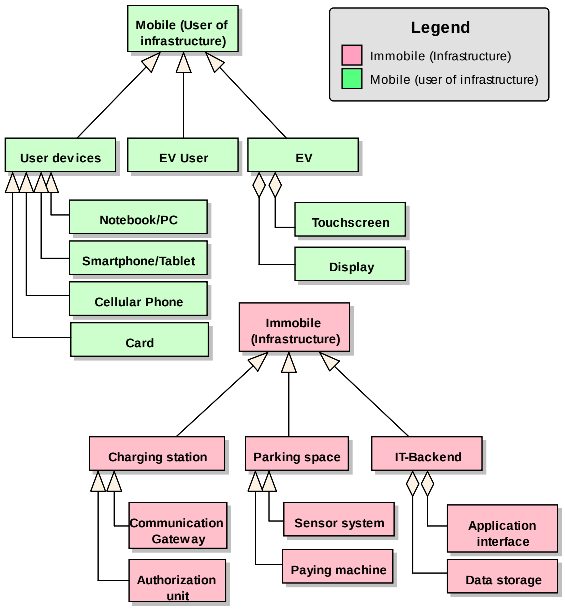

Figure 3. Main components of EM-ISA's element model

A high-level description of the element layer at the fix and intersection point of e-mobility is shown in figure 4. It distinguishes between domains, but not the zones to which elements will belong, since most of them can be used in all zones.

C. *Linking EM-ISA layers*

In order to prevent isolated description and models within each of the layers, the linkage between EM-ISA layers is essential. In general, each model of one layer is able to be related to the model of all other layers. However, the linkage is most intuitive for layers being closely together. Top-down, the models can be linked as follows (examples):

- Business → Function: matrix that reveals for which business or use case which function is needed.
- Function → Data: diagram with data objects as inputs and output of the functions.
- Data → Communication: diagram that depicts which data object or model is used by what communication standard or is transferred via what communication link.
- Communication → Element: communication links are plotted as relation between elements.

The last example is shown in figure 4. It also reveals that that several level of abstractness can be integrated via UML generalization relations within such a diagram in EM-ISA.

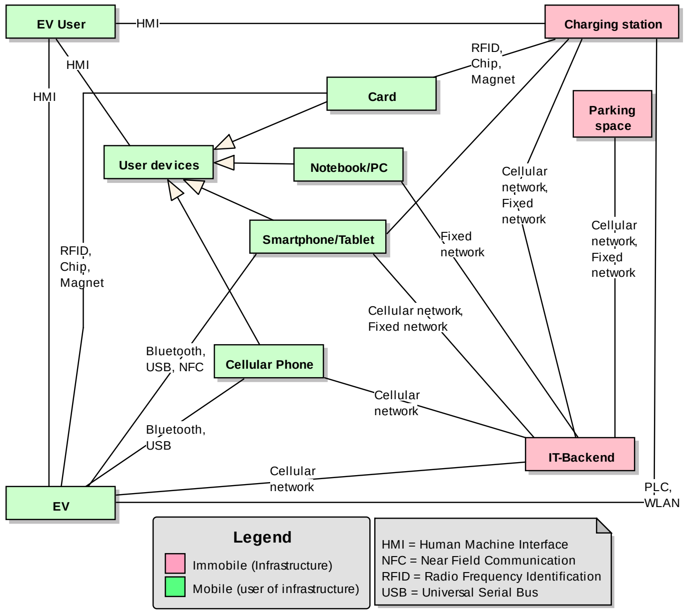

Figure 4. Example for interlinking EM-ISA layers: communciation and element.

IV. Conclusion and Outlook

This paper identified a lack of support when organizations create information systems for new business models at the fixed and intersection point of individual E-Mobility, i.e. the energy transmission between EV and power grid. To close this gap, a generic Information System Architecture for E-Mobility

(EM-ISA) was developed and presented. EM-ISA is derived from the currently developed SGAM and tries to integrate with it. Further descriptions of links between the EM-ISA dimensions as well as the disclosure of independencies with existing and evolving standards (IEC15118 or OCPP) are needed. These efforts are expected to further increase the application of EM-ISA so that efficient information system can help to implement innovative and e-mobility services.

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