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Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships

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ABSTRACT

Electric vehicles (EVs) present efficiency and environmental advantages over conventional transportation. It is expected that in the next decade this technology will progressively penetrate the market. The integration of plug-in electric vehicles in electric power systems poses new challenges in terms of regulation and business models. This paper proposes a conceptual regulatory framework for charging EVs. Two new electricity market agents, the EV charging manager and the EV aggregator, in charge of developing charging infrastructure and providing charging services are introduced. According to that, several charging modes such as EV home charging, public charging on streets, and dedicated charging stations are formulated. Involved market agents and their commercial relationships are analysed in detail. The paper elaborates the opportunities to formulate more sophisticated business models for vehicle-to-grid applications under which the storage capability of EV batteries is used for providing peak power or frequency regulation to support the power system operation. Finally penetration phase dependent policy and regulatory recommendations are given concerning time-of-use pricing, smart meter deployment, stable and simple regulation for reselling energy on private property, roll-out of public charging infrastructure as well as reviewing of grid codes and operational system procedures for interactions between network operators and vehicle aggregators.

1. Introduction

The integration of plug-in electric vehicles (EV) in electric power systems poses new technical, economic, policy and regulatory challenges (Galus et al., 2010; Pieltain Fernandez et al., 2011; Momber et al., 2011). Due to energy efficiency and environmental advantages over conventional transportation, the future of EVs seems promising (EPRI & NRDC, 2007). However there are still important technological and economic barriers mainly related with efficient and affordable storage technologies that will hopefully be resolved in the near future (Peterson et al., 2010).[1]

Regarding the environmental advantages of EVs over conventionally propelled transportation, i.e. fossil fuel dependent internal combustion engines; it has to be kept in mind that they depend on the generation mix of electricity production at the time of charging. In fact timing is one of the reasons for coordinated charging. However, certain studies conclude that, even in rather unlikely but most CO_2 intensive scenarios, both annual and cumulative GHG emissions could be reduced significantly, due to a certain electrification level of the car fleet under analysis (Electric Power Research Institute, 2007). It is assumed that agents are profit oriented and would act in response to economic signals such as retail tariffs or market prices for electricity and could then exert different levels of control on the charging of the contracted final EV users. The pricing of externalities caused by electricity production however is assumed to be represented in wholesale energy markets.

Abbreviations: A, ampere; AC/DC, alternating current/direct current; AGC, automatic generation control; BMS, battery management system; CC, controlled charge; CP, charging point or charging post; CPM, charging point manager; DER, distributed energy resources; DG, distributed generation; DSO, distribution system operator; EMC, energy management controller; EREV, extended range electric vehicle; EU, European Union; EV, (plug-in) electric vehicles; EVC, on-board electric vehicle controller; EVM, electric vehicle meter (on- or off-board); EVSA, electric vehicle supplier aggregator; EVSE, electric vehicle service equipment; FCM, final customer meter; HO, home/domestic; HV, high voltage; ISO, Independent System Operator; kW, kilowatts; kWh, kilowatt-hour; LV, low voltage; MV, medium voltage; PR, private area with public access; PU, public area with public access; SA, supplier/aggregator or retailer; SoC, state of charge; RES, renewable energy source; ToU, time of use; TSO, transmission system operator; UCO, uncontrolled charge; V, volt; V2B, vehicle to building; V2G, vehicle to grid; V2H, vehicle to home

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[1] Numerous research and academic institutions together with governments recently have elaborated a significant number of studies on EV technology, see for instance EPRI&NRDC (2007), Valentine-Urbschat and Bernhart (2009), Electrification Coalition (2009), IEA (2009), National Academic of Sciences USA (2009), and The Royal Academy of Engineering UK (2010).

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The European Parliament recently adopted a resolution for the promotion and support of electric vehicles for personal transportation (EU, 2010). In this resolution different actions are proposed in order to achieve a single European EV market. Among those actions the call for international or at least European standardization of charging infrastructures and technologies, including smart grids, with open communication standards, should be highlighted.

The currently perceived purchase premiums compared to internal combustion engines are widely being discussed and a multitude of different policy schemes to foster EV adoption is evaluated. A comparative study shows that from a user perspective one time support at the initial investment is highly appreciated. However, recurring instruments like an annual tax benefit are more effective yet usually smaller in volume (Kley et al., 2010a).

In addition to technological developments and policy measures, regulatory issues related to investment and deployment of the required infrastructure need to be formulated and adequately solved. Coherently, there is a need for discussing how and which agents should be authorized to provide EV charging and pricing of those services, as well as how EV storage capability could be appropriately marketed to provide vehicle-to-grid (V2G) services (Kempton and Tomic, 2005). However, an accurate calculation of the benefits is a complex task in order not to misunderstand or overstate the potential (Dallinger et al., 2011; Andersson et al., 2010).

Therefore, still many questions remain to be answered within a consistent regulatory framework considering rules and players in existing electricity markets. Setting the structure for a cost-effective development and deployment of the necessary charging infrastructures is a difficult task given the early stage of the industry. Predicting all possible occurrence of economically viable and socially desirable infrastructure development in accordance with smart grid requirements poses a great challenge for decision makers. It would involve determining the financing structure to be collective or private. Investment costs could be socialised among electricity consumers or more generally among all tax payers. Alternatively they could be recovered through EV user payments only. Furthermore it is yet unclear which agents should be responsible for developing them as well as whether the business would be bound to strong monopolistic regulation or characterized by competitive components. None of these questions is answered in Kley et al. (2011). Depending on the intended outcome, the charging infrastructure could be considered a fully regulated monopoly, as transmission and distribution grids are, or a corporate entity allowed owning and deploying charging infrastructure.

All of the above raised issues can be extended to specific infrastructure capable of using EV storage for grid service provision V2G as peak power or ancillary services, frequency regulation and power reserves. However, V2G contains yet another challenge. The conditions to incentivize vehicle owners to adopt direct charging management mechanisms and yield control over the battery system are yet to be found Pecas Lopes et al. (2010). According to that, a regulatory framework needs to maintain the utility's obligation to provide reliable electric service balanced with a vehicle owner's desire to sustain control in case of personal need.

As electricity for charging EVs is used for transportation, there are various controversial arguments for a price differentiation from other electricity consumption, for instance including taxes for development of transportation infrastructure or by the contrary giving it subsidies because of carbon emissions reduction relative to traditional internal combustion propulsion systems for transportation.

As an example of these issues, in California, the Public Utilities Commission has opened a rulemaking process, in which a number of issues are proposed for consultation with stakeholders. It is yet to be determined (i) how to implement obligatory variable tariffs, (ii) legal status of electricity resellers, (iii) incentive creation for users to adopt remote charge control of valuable[2] batteries, and (iv) allocation and recovery of investment in infrastructure in a fair non-discriminatory framework (CPUC, 2010a). Furthermore, there exists an intense discussion about critical metering policies in terms of metering arrangements (single, sub- and separate metering) and their implications on cost, installation time, and billing flexibility (CPUCb, 2010b).

In this paper, a conceptual framework is developed in order to provide the basis for giving an answer to the previous main issues of regulating future large scale EV integration. The regulatory framework for the organization of the European internal electricity market (EC, 2009) is taken as reference framework in which concepts must function. However, many of the proposed concepts remain partially valid for other markets or regulatory structures. Further on, different charging modes for providing energy and V2G services are identified and presented in detail.

The paper is organized as follows. Section 2 recapitulates each role of the existing involved agents in the electricity sector. Consecutively, the new agents related to the business of charging EVs are introduced to the reader. Section 3 introduces definitions of grid and charging infrastructures. Section 4 identifies metering, communication and control equipment for charging EVs. In Section 5, charging modes associated with charging at private parking sites as well as for public use are defined. Different basic charging modes, from electricity supply at home to public and private[3] charging stations are proposed in Section 6, while Section 7 provides alternative solutions of the basic variants. The same type of business models are revisited for providing V2G services in Section 8. Finally, conclusions and some policy recommendations are given in Section 9.

2. Agents

In this section, first, existing agents of the electricity sector are defined according to the functions assigned by EU legislation (The European Parliament, 2003). Then, new types of agents who would play relevant roles in developing EV charging infrastructure and providing charging services are defined: the EV charging point manager (CPM) and the EV supplier-aggregator (EVSA).

2.1. Existing agents

Distribution system operator (DSO): is the owner and operator of the distribution grid. It is assumed that distribution is legally unbundled from generation, transmission and particularly from supply and retail. Therefore, DSOs cannot trade energy. They only provide network services and are fully regulated monopolies.

Supplier or retailer(SA): is the agent who sells energy to final customers, the electricity end consumers. In countries where distribution and supply have been unbundled, final customers remunerate the supplier for the service, who in return procures the energy and pays the DSOs regulated charges for grid services and other system costs. In other countries without retail markets,

[2] If you compare electric vehicles (EREVs, PHEVs and BEVs) to cars equipped with conventional internal combustion engine based propulsion systems amongst others, one of the major disadvantage is the increased vehicles mass due to lower energy densities in the electrochemical (e.g. lithium ion) battery packs. To attain the needed levels of power and energy, that are expected by vehicle consumers concerning range and driving characteristics, the batteries have to be sized such that at current and projected production costs the EVs are going to be more expensive than conventional vehicles and the batteries will most likely present one of the most valuable components of the car (Kalhammer et al., 2007).

[3] Private refers to either domestic or commercial (corporate), i.e. non-state owned and not public.