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Assessment framework for EV and PV synergies in emerging distribution systems

Aymen Chaouachi [a,*], Ettore Bompard [a], Gianluca Fulli [a], Marcelo Masera [a], Michele De Gennaro [b], Elena Paffumi [b]

[a] Institute for Energy and Transport, Joint Research Centre of the European Commission, Petten, The Netherlands
[b] Institute for Energy and Transport, Joint Research Centre of the European Commission, Ispra, Italy

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ABSTRACT

The next-generation electricity grid ("smart grid") is expected to integrate interoperable technologies – particularly in the energy, transport, information and communication fields – with the aim to increase reliability, affordability and sustainability considering at the same time, distribution systems and market operation. In order to gauge the implications of the anticipated paradigm shift for the electricity system, new reference architectures and assessment methodologies shall be developed to properly capture the interactions between the different actors (especially utilities, operators, energy aggregators, end-users, etc.) and technologies to value and allocate the costs and benefits of such transformation. Against this background, this paper proposes a conceptual architecture and an assessment framework to explore how high penetration scenarios of electric vehicles and intermittent renewable generation can complement each other in emerging distribution networks. We start from the identification of the smart grid functionalities to be implemented in a system with distributed power injections under the need to supervise and coordinate myriads of decentralized and interoperable energy sources and actors. Relying upon the proposed smart grid conceptual architecture, we develop an assessment framework to maximize the renewable electricity and electric vehicle penetration for given electricity and transport systems. The application of the proposed assessment framework to a realistic case study, representing the distribution and mobility systems of a typical mid-size Italian city, illustrates how some of the limitations and constraints of the current electricity network operation and design approaches can be addressed and overcome. We show how integration of substantial amounts of energy production and electric-based transport technologies can be achieved while improving the reliability and sustainability performances of the emerging power systems.

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* Corresponding author.
E-mail address: a.chaouachi@gmail.com (A. Chaouachi).

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1. Introduction

Today's transportation system in the European Union (EU-28) accounts for 23% of CO_2 emissions, 72% of which originates from road transport [1,2]. With a view to achieve a more sustainable and energy secure society, the deployment of Electric Vehicles (EVs) for ground transportation has been drawing increasing interest due to the potential of reducing greenhouse gas emissions and fossil fuel dependency. Nonetheless such postulation can be relatively erroneous and deceptive, as the avoided carbon emissions from the petrol/diesel conventional engines, displaced by EV, could be even offset by the emissions of fossil fuel based power plants, supplying the EVs and covering grid losses. Consequently, for EV deployment to be considered as an emission alleviating solution, a low carbon electricity network with a substantial penetration of Renewable Energy Sources (RES) shall be in place [3]. Furthermore, an ideal scenario for the success of EVs uptake would entail a distribution grid providing electricity charging services at any time and any place. Such requirement, clearly, conflicts with the capabilities of the current distribution network, particularly at peak hours. On the other hand, an efficient penetration of distributed intermittent RES is related to the ability of injecting all the generated power while satisfying all the network operational constraints. The flexibility, in terms of power/time control, of EVs can be of great advantage when addressing the issues mentioned before: in fact, from the operational point of view, the synergy between EVs and distributed RES could be a major asset for implementing efficient Demand Side Management (DSM) within the smart grid. Various studies had already acknowledged and investigated the EVs potential in DSM enhancement as flexible/controllable loads to take part in load shifting and in reshaping the demand profile. In fact, the time-shifted recharging could involve off-peak valley filling, hence resulting in a significant improvement of the load factor [4–10]. Particularly, Pietlain et al introduced an EV impact assessment [11] against penetration scenarios and proposed charging strategies within electricity distribution networks with the aim to evaluate the investment costs and electricity losses. Richardson et al proposed an impact assessment of varying penetrations of electric vehicles on low voltage distribution systems [12], the authors demonstrated that even for relatively modest levels of electric vehicle charging, both the voltage and thermal loading levels can exceed safe operating limits. Nunes et al has evaluated an Energy plan for the horizon 2050 in Portugal [13] considering the added value of complementarities between undispatchable generation sources and electric vehicles, results had shown that the foreseen targets would require high penetration levels of Photovoltaic generation and Electric Vehicles (EV) charging infrastructures. Masalkina et al developed a framework energy consumption model of EV [14], to emulate the mobility patterns against performances and electricity consumptions based on real mapped data and increasing penetration scenarios.

While much research has been devoted to separately assess the EVs and RES penetration challenges at the distribution level in terms of DSM and power quality support, little attention has been paid to the investigation and identification of synergies mechanisms and technical requirements aiming to accommodate and assess the mutual benefits of efficient interaction between RES and EVs in terms of intermittency mitigation and DSM [15,16].

This paper proposes a conceptual smart grid framework and assessment methodology, from interoperability and functionalities prospective, to enable decentralized operational synergy between intermittent Photovoltaic (PV) generation and EVs, based on coordinated EVs charging. The proposed methodology is tested with a real distribution system of a city in northern Italy, where different PV and EV penetration scenarios are assessed against charging behavior variants using baseline temporal and spatial Italian road traffic patterns [17]. The assessed EV charging consists of uncoordinated and coordinated charging strategies, the latter being based on technical and market control variance. A simulation on a real case study provides a quantitative illustration of the expectations of such EV–PV synergy in terms of benefits, functional interoperability and system integration requirements.

2. Integration of EV and PV in emerging distribution systems

In the foreseen distribution networks: the intermittent power injections from PV, the conventional power generation and the load demand, including EV charging solicitation, must be matched. Fig. 1 reports – in per unit (p.u.) – "generic" electricity PV generation profile, electricity load profile and conventional vehicle parking distribution profile within the province of Modena (the latter profile is used as a proxy to identify the most likely charging availability periods).

We assume that the behavior of the drivers in terms of motion/parking, depicted in Fig. 1 for traditional combustion engines [17], will be similar to the EVs. Supposing that the EVs are mainly charged subsequent to home arrival in an uncoordinated fashion, little mutual benefit can be drawn from the EV demand and PV generation interaction. In fact, the EV peak load demand largely overlaps with the late afternoon electricity peak demand, when PV generation is mostly not available. Conversely, the PV generation peak occurs at a rather high mobility time or charging unavailability period, not hinting at straightforward charging opportunities.

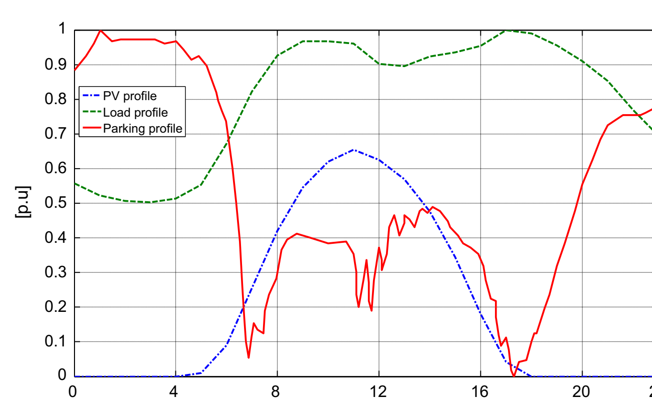

Fig. 1. Normalized PV generation and load profiles (pu) and share of parked vehicles over 24-h.