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The Nikola Project

Intelligent Electric Vehicle Integration

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Abstract— The electric vehicle (EV) has certain properties that elevate its relevance to the smart grid. If EV integration is to meet its potential in supporting an economic and secure power system and at the same time lower the operating costs for the owner, it is necessary to thoroughly and systematically investigate the value-adding services that an EV may provide. The Danish Nikola project defines EV services as the act of influencing the timing, rate and direction of the power and energy exchanged between the EV battery and the grid to yield benefits for user, system, and society. This paper describes the services identified by Nikola and shows how the project aims to evaluate and demonstrate them in simulations and field tests. This paper is both meant to give the reader insights and inspiration from the project approach, but it is also meant as an encouragement for cooperation and feedback.

Index Terms—Electric Vehicles, Project, Enabling technology, Smart grid, Standardization

I. INTRODUCTION

Of the topics that fall under the umbrella of smart grid research, distributed energy resources (DER) integration is one of the larger of these disciplines. This area covers the diverse number of flexible loads and small productions units throughout the grid which will help support an economical and secure power system with a large renewable content.

Considering the many different types of DERs, one could be said to have a special potential, namely the electric vehicle (EV). The EV has properties that elevate its relevance to the smart grid in that it is:

1. A **large** load compared to other household-attached applications;
2. Expected to be grid-connected and available for long periods of the time with a high degree of **flexibility**;
3. A **quick-response** unit with an attached **storage** and potentially with **bi-directional power** flow capabilities (V2G).

The above properties can be used to support a set of power and energy behaviors which can prove useful to the power system. These are illustrated in Figure 1.

Figure 1. EV power and energy behaviors.

In the figure, *Adaptive charging* (A) means that charging is delayed or advanced in time based on, e.g., energy cost or renewable content. This behavior corresponds to the concept widely known as “smart charging”. *Energy backup* (B) means to charge some quantity of energy to be delivered back to the grid at a later time. Finally, *Ancillary services* (C) covers

The Nikola project has received 10 MDKK of public financing through the ForskEL program. Project partners: NUVVE, EURISCO, SEAS-NVE, DTU.

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seas-nve

NUVVE

DTU

continuous short-duration charging and discharging power operations to balance the grid.

The above behaviors may, isolated or in combination, be used in a long list of specific applications, in this paper referred to as “services” which will be explained in the next chapter.

The final goal of utilizing these behaviors is, from a societal and grid point of view, to minimize the cost of operating the overall power system. For the individual EV owner, these behaviors can reduce the operating costs of electricity thereby strengthening the competitiveness with ICE vehicles.

This goal is what the Danish Nikola project set out to achieve. The project will thoroughly investigate the services which supports a synergetic relationship between the EV and the power system; to explore the technologies that can enable them; and finally to demonstrate them through both simulations and in-field testing.

The project is sponsored by Danish public service obligation (PSO) funds managed by the Danish TSO Energinet.dk and will run from 2013 through 2016. The aim of this paper is to describe preliminary outcomes of Nikola and describe the further targets and methods of the project to inspire, but also in order to get feedback from academia and industry. The “Service catalogue” section describes the services defined by Nikola. Section IV, V and VI, namely “System-wide services”, “Distribution grid services”, and “User added services” describe the services in more detail and finally section VI, “Enabling technology”, describe the development and standardization efforts which the services rely on.

II. RELATED ACTIVITIES

A number of European and international EV projects have already dealt with EV smart grid integration topics relevant to the services defined by Nikola. One such project is the Danish EDISON project [1] which investigated a broad set of areas relevant to EV integration. In EDISON it was demonstrated how the charging of EVs could be coordinated with the energy prices on the Nordic spot market [2], [3].

In the Australian “Demand management of electric vehicle charging using Victoria’s Smart Grid”, a number of electric vehicles, operated by participating households, were controlled to help support the local distribution grid while at the same time observing system-wide time-of-usage (TOU) tariffs.

At the University Of Delaware, the V2G program [4] headed by Professor W. Kempton has successfully demonstrated how EVs can participate in regulation services using a fleet of vehicles with bi-directional power capability [5].

O. Sundstroem and C. Binding from the IBM research institute in Zurich, Switzerland have published a number of high-quality papers on EV charging optimization. The authors explore the topic in both width and depth, by considering numerous stakeholders and technical constraints that must be taken into account [6] while at the same time demonstrating the use and performance of mathematical methods [7].

Professor J. Lopes from the University of Porto, have made large contributions to EV integration research with several papers and reports on distribution grid impacts of EVs and how charging can be planned to mitigate congestion [8].

There are countless other project and programs from which Nikola has drawn inspiration and experiences [9]-[15]. The purpose of Nikola is to gather, evaluate, and possibly combine services and demonstrate them in a North European context.

III. SERVICE CATALOGUE

Using the energy and power behaviors described above, the EV can support a number of services. In Nikola, the formal definition of “Service” is the act of influencing the timing, rate and direction of the power and energy exchanged between the EV battery and the grid to yield benefits for user, system, and society. In Nikola these services are divided into categories according to the level of the power system to which they add value. Therefore the services are described as either *System-wide services* or *Distribution system services*.

The project also includes *User-added services* but whereas the first two groups describe power and energy services, the latter describe services that, through informatics, will grant the end user access to information and control regarding the charging process.

As part of the project the consortium has identified a total of sixteen services as shown in Figure 2.

Figure 2. Nikola services.

These services have been evaluated by an external team of academic and industry reviewers. The reviews have provided Nikola with a set of chosen services which will be investigated in greater detail by the project. Through further analysis and experiments, the purpose is to evaluate the technical and economic implications of each service and demonstrate their use.

IV. SYSTEM-WIDE SERVICES

This category of services can aid in maintaining a cost-efficient, secure power system with a high degree of renewable production. Such operational and strategic targets are in Denmark managed by the transmission system operator on a system-wide (≥ 132 kV) level via the ancillary service (A/S) market. Nikola will both investigate services that can be provided through current A/S products as well as services not yet enveloped by a market product.

The project will evaluate the economic viability of participation in current markets and form recommendations for future market products.

Nikola System-wide services:

Frequency regulation–Normal: Also called Primary Regulation or Frequency Containment Reserve. The ancillary service that keeps the frequency in an interval around 50 Hz. Vehicles may be able to compete with or replace traditional generators as providers of frequency regulation.

Frequency regulation–Very fast: A new type of frequency regulation that offers ramping times and precision that go beyond what traditional generators can provide.

Secondary regulation: Also called Frequency Restoration Reserve. The ancillary service that restores the frequency to 50 Hz after deviations and replaces frequency regulation when the latter has either stopped a deviation or reached its limit.

Tertiary regulation: Also called Replacement Reserve. The ancillary services that replaces secondary regulation, typically with a higher requirement to energy capacity and delivery timescale.

Synthetic inertia: Inertia refers to the stored rotational energy in traditional generators. EVs, taking advantage of the fast chemical reaction that characterizes the Lithium storages, can mimic this effect.

Adaptive Charging: Charging is delayed or advanced in time based on, e.g., energy cost or renewable contents. This type of service is sometimes referred to as “Smart charging”

MORE (Mother of all Regulation): A new type of ancillary service that includes all the traditional types of regulation. A larger fleet of EVs could both respond immediately to deviations in frequency, but could also help with regard to longer term energy balancing.

Studies of primary frequency regulation and adaptive charging services have begun at the DTU Risø research facilities in Zealand, Denmark. Figure 3 shows the research facilities and the V2G enabled vehicle used in the experiment.

Figure 3. Nikola test site at DTU Risø, Converted Toyota Scion

In [16] S. Martinenas et al. shows how the EV can provide fast frequency regulation for longer periods of time. It is also shown how the vehicle can respond to dynamic prices as used in the large EcoGrid EU project.

Figure 4 illustrates one of these project experiments where the black line represents the system frequency, the red line is the vehicles response in terms of charging (negative) or discharging (positive) power and the green line is battery SOC. These are the first tests of their kind performed in Denmark.

Figure 4. Frequency response by a V2G enabled EV.

The symmetry between frequency and current shows how the EV will immediately adjust its (dis)charging behavior in proportion to the frequency deviation at any given time. Also, it can be seen that the SOC is kept relatively stable throughout the hours due to the close to equal number of under- and over-frequency events.

V. DISTRIBUTION GRID SERVICES

In this service group, Nikola investigates the integration of the electric vehicle (EV) in the distribution grids (< 132 kV) as part of the operational and strategic targets of a distribution system operator. Parameters addressed include voltage, thermal and reactive power limits.

This area also cover islanded and microgrid scenarios where EV services are used to maintain a stable and secure operation.

Finally Nikola investigates "mixed-DER" scenarios where EV battery (dis)charging is coordinated with the behavior of other types of distributed energy resources such as photovoltaic micro-combined heat and power units, heat pumps, and home appliances.

Nikola Distribution System services:

MV-LV Transformer and lines overloading: The shift of energy consumption from other energy forms to the electrical one, along with the penetration of EVs, will show the need for MV and LV networks capabilities. That could lead to over-loading of the transformer and of the cables, leading to low voltages violation (which lead to further over-loading in case the load characteristic is not voltage dependent).

Proper EV discharging management (or coordinated charging management) could help mitigating this aspect.

LV overvoltages management: Increasing amounts of distributed generation in the LV feeders could cause over-

voltage in local part of the network. Several feeders under the same transformer could potentially face different voltages profiles (over-voltages in one feeder and low voltages in others). Proper EV discharging management (or coordinated charging management) could help mitigating this aspect.

LV network balancing: The possibility of performing single phase charging/discharging (10A or 16A – 2.3 kW or 3.6 kW) could unbalance the LV network. However, proper EV charging or discharging management can help to mitigate this aspect.

LV congestions due to fast Charging Station: The need of having EVs recharged far from home will require fast charging station (50 kWx4) which may need to be installed in areas where the network could be weak. Proper EV charging could limit the power request and therefore problems to the network.

Islanded microgrid and black start: The possibility to have one or a set of EVs being able to sustain a small power system could be a valuable resource (either under normal conditions or in emergency situations). The inverter equipping the EV must be able to operate in islanded mode (V/f) or, if able to receive just a PQ reference, to be equipped with a “traditional” droop controller which is able to set the PQ references according to how frequency and voltage behave in the local power system.

The system architecture and the interaction between the different entities are shown in Figure 5. The DSO sends information to the aggregator in order to require a specific service to be activated. The aggregator sends information back about availability and deployed capacity. The aggregator has full overview of the status of the EV and information (charging status, power flow from/to the battery, SOC, connectivity) are sent back every minute. Set-points on the other hand are sent whenever a specific amount of active or reactive power is required. The DSO gets information on the status of the network at the transformer level and eventually at the end of the different LV feeders.

Figure 5. System architecture for distribution system services

Two local feeders in the Danish city of Borup are being used as test sites for the project. Based on these feeders and measured consumption data, a Matlab SimPowerSystems model have been made which are used for EV voltage

support analysis studies by K. Knezović et al. in [17]. A frequency control study is carried out by A. Zarogiannis et al. in [18]. The feeders and model is shown in Figure 6.

Figure 6. Borup distribution lines used in Nikola

VI. USER ADDED SERVICES

This service group pertains to the electric vehicle (EV) owner and her involvement in EV services. Nikola will first investigate the behavioral patterns of EV owners to establish to what degree flexibility is allowed to manipulate charging, e.g. how often and for how long the EV will connect to the power system and the predictability of these plug-in periods. The studies cover both private and fleet driving. The services investigated under this topic are primarily focused on how to understand, inform, and empower the EV user before altering the (dis-)charging behavior of the vehicle batteries. Nikola touches upon how service participation by the EV owner will yield a sufficient economic incentive while also providing a convenient and easy solution.

Nikola user added services:

Charging flexibility assessment: An electric vehicle can be said to have “charging flexibility” if the time available for charging (between plug-in and plug-out) is sufficiently long compared to the time needed for charging and if the charging period itself is sufficiently predictable and recurs according to specific patterns.

Charging information: A number of web-enabled devices should give the user access to charging information. This service should identify the pieces of information that are most relevant for the EV user when controlling the (dis)charging of the EV.

Charging management: By using historical data about the user it is possible to minimize user involvement in smart charging management. The user can simply be presented with some simple options based on a backend systems ability to analyse and predict the behavior of the user.

Vehicle-To-X (V2X): The EV owner may have a need for electric energy in places where access to the general electricity grid is not possible or practical. Access to the battery energy for applications other than driving could be a service offered to the EV owner.

Nikola will use data from a group of RWE charging spots owned by the City of Copenhagen. The site shown on figure 7 will provide Nikola with insights into fleet charging and associated charging flexibility.

Figure 7. Copenhagen test site with RWE EVSEs

V2X applications have been tested by Nikola at the large Danish Roskilde Music Festival where an EV has been used to power a portable demo laboratory.

VII. ENABLING TECHNOLOGY

The cornerstones of Nikola are the technologies that need to be developed for EVs, charging spots and backend systems to enable EV services. Special attention is given to the intelligent controllers that will influence the (dis-)charging of EV batteries, their software and hardware, and the communication between them.

Other technologies that will aid EV services such as fast A/C charging stations, mobile apps, and in-car information systems also fall within the scope of the project.

While some services may be demonstrated with existing EVs, others require monitoring and control capabilities not yet available. For such services a fleet of converted Citroen C1s (See figure 8) have been acquired and will be upgraded to satisfy the needs of the project.

Figure 8. Nikola project converted C1s

Similarly, the project will use a combination of OEM and custom-built EVSEs for carrying out the demonstrations. Nikola uses technology developed by its partners NUVVE and EURSICO in the vehicles. NUVVE will provide their V2G technology for support of bi-directional power capabilities while EURISCO will provide an advanced vehicle monitoring and logging system.

An important goal for the project is to tie its technology development to current European and world-wide standardization efforts, especially applicable standards such as IEC 15118 and IEC 61851. It is hoped that Nikola may help validate EV communication standards in regard to smart grid integration and to ensure that a long list of services will be sufficiently supported by future protocols and data models.

VIII. CONCLUSIONS

This paper has introduced the Nikola project with an emphasis on the catalogue of services that have been defined. Over the duration of the project a chosen subset of these services will be analyzed and demonstrated to evaluate the following parameters:

1. Technical complexity.
2. Standardization needs.
3. Framework/regulatory complexity.
4. Economic incentives (system - society - user).
5. Possible battery impact.
6. Need for V2G capability.
7. Possible implications for user.
8. Need for aggregation.

The paper has given a few examples of the first research carried out. Further investigations will make it possible to determine which of the services holds the greatest promise and should be pursued by academia and industry. It is hoped that the findings presented can be used to release the potential of EVs and promote and support the intelligent integration of EVs into the power system. More: www.nikolaproject.info.

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