Estimating Network Impact of Charging Electric Vehicles in Smart Grid

Brenda Vilas Boas, Jean-Charles Grégoire and Aldebaro Klautau

Abstract— **Within smart cities, electric vehicles (EV) rise as a sustainable transport and mobility option. Introduction of EVs to the grid requires control and management of electrical load where information and communication technologies (ICT) are the key to such interaction. This work presents a charging scenario and results from a tool built on MATLAB to estimate the communication load for charging electric vehicles in a fleet.**

Keywords— **Vehicle to Grid, Smart grid, Fleet charging**

I. INTRODUCTION

Smart cities demand, among others, intelligent and sustainable environments to reduce environmental impact and offer a high quality of life for citizens. Therefore, the advent of grid-connected EVs is an important step toward smart and sustainable cities. However, uncontrolled introduction of EVs to an electric grid can be catastrophic given the increasing peak demand of electricity [1].

Smart grids propose a more efficient, reliable and sustainable way to supply, distribute and deliver electricity by aggregating advanced ICT to the grid [2]. Within smart grids, vehicle-to-grid (V2G) application will enable bidirectional communication and power delivery between EVs and power grids. Besides charging, EVs will be able to provide ancillary services and storage capability allowing integration of renewable energy resources to the smart grid [3]. For V2G, EVs will be integrated into the grid through virtual power plants (VPP) in which EVs are clustered and controlled as distributed energy resources (DER) [4].

ICT play an essential role collecting information for smart grid since information will allow management of EV charging and V2G services. Most EVs may be charged in various different locations, such as their home premises and office parking lots and it is therefore important to ensure compatibility of ICT [5]. Therefore, standards were developed for V2G, among them IEC 61851 and ISO/IEC 15118 where the later defines a high level communication protocol complementing the low level communication protocol defined in the former [6].

This paper presents a tool on MATLAB to estimate the communication load for charging an EV fleet with regard to the available electricity on the grid. Further, a fleet scenario is built for testing purposes.

II. ESTIMATING THE COMMUNICATION LOAD

On smart grids, EVs will establish a client-server interaction with an electric vehicle supply equipment (EVSE) which will allow message exchange for, among others, discovery of services, user authentication, pricing, status of the grid, set charging profile and billing [7]. The EVSE relies on SOC message updates to adjust the charging rates; thus, such updates are critical for EV charging applications. Each charging attempt has a fixed number of messages for initialization, vehicle authentication, energy transfer authorization, and metering purposes. Besides, the quantity of SOC messages will vary according to the charging duration [5]. Thus, charging duration is a key factor to determine the total communication load of EV charging application.

Following the model proposed by [5] for calculating the total communication load when charging EVs, the communication load, in bytes, for charging the l-th vehicle is given by equation (1) where l_{fixed} is the length of fixed messages in bytes, $l_{variable}$ is the length of variable messages, n is the quantity of SOC messages and l_{SOC} is the length of the SOC messages in bytes.

$$l_i = l_{fixed} + l_{variable} = l_{fixed} + (n \times l_{SOC}) \tag{1}$$

EVs will not freely connect to the grid, an admission control scheme will be adopted as in [8] where vehicles could be partially charged according to the electricity available for charging at the utility side. Hence, the admission method needs to be taken in consideration when calculating the total communication load of an EV charging system. The energy needed to charge M EVs ($E_{consumed}$) will be estimated by the product of the average system electrical load (ρ) and the unblocking probability $(1-B)$ of the utility, the activity factor (α) may be included for the sake of the admission control method [5], [8].

$$E_{consumed} = \alpha \times \rho \times (1-B) \tag{2}$$

The size of the battery, type of charger used, and residual energy level are the major conditions to define the charging duration of a particular EV. As proposed by [5], the number of SOC messages for a particular vehicle i, n_i, throughout the charging section will depend on the time to fully charge (T) the i-th vehicle, the time to actualize the SOC message (t_{SOC}) and the ratio of battery (β) to be charged on the i-th vehicle. The reporting interval of SOC messages may vary between 5 and 30 min depending on the utility‘s choice. Therefore, the overall communication load for an EV charging system can

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be calculated as in equation (3).

$$L_{total} = M \times l_{fixed} + \sum_{i=1}^{M} \frac{\alpha \times \beta_i \times T_i}{t_{SOC}} \times l_{SOC} \qquad (3)$$

Based on equations (2) and (3) a tool was built in MATLAB to estimate the activity factor and the communication load given an energy budget for charging a fleet of M EVs.

III. CHARGING SCENARIO

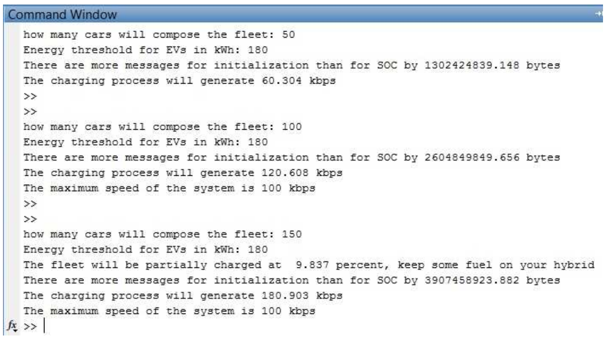
In order to analyze the functionality of the developed tool, a fleet scenario is presented. The Toyota Prius model 2008 hybrid with a Hymotion L5 plug-in conversion module from A123 Systems was chosen to compose our mail pick-up and delivery fleet. This battery pack with 5kWh capacity [9] that supports 30 to 40 miles driving on a single charge will be recharged at SAE J1772 level 2, 240VAC, using a charging point that supports level 1 and 2 charging and supports user identification and billing. A PLC module of 100kbps is used for all communications. According to tests performed by [10], an overnight 100% recharge of an L5 battery, which, for a level 2 recharge can take 6 to 8 hours, will generate (about) 2,141,876 messages of a 20 bytes length, of which 371,500 messages are exchanged during the charging period.

A postal delivery fleet has an average postal route of 50 Km [11] what corresponds to about 31 miles. Assuming that there are 50 cars in the fleet and each car does one postal route per day, the L5 module will be probably fully depleted at the end of the day. The cars would attempt connection to the grid for recharging in a Poisson manner with mean of $1/4$ of the size of the fleet per hour; and the full charge will take 6 hours. The utility threshold will be set to 180 kWh, the blocking probability is set to 2% and the batteries will require charge between 90% and 100%. According to the model presented on II, if the utility threshold is exceeded, an activity factor will be calculated based on the difference between the energy required and the energy available. The length of the messages and the quantity of fixed messages exchanged are set as 20 bytes and 1302493 messages, respectively, based on experiments performed by [10]. Indeed, the SOC messages are updated every 5 minutes [5]. The results are presented on the next section.

IV. RESULTS

The results are presented in the MATLAB command window and the script was first run for a fleet of 50 vehicles, after it was re-run for 100 vehicles and 150 vehicles on the fleet in order to test and analyze the constraints of the system.

From figure 1, we observe that a fleet with 50 vehicles does not reach the system threshold, neither data rate nor energy required to charge the whole fleet were reached. When maintaining the energy threshold and increasing the fleet size to 100 vehicles, the data rate for the charging process is higher than the data rate of the system; therefore, congestion is likely to occur and a warning message is shown to the user.For a fleet with 150 vehicles and keeping the systems limits, both energy and data rate threshold are reached. Then, warning messages are shown to the user regarding the reach of the maximum data rate and the partial charge of the fleet, 9.82%. Because of the partial charge, a hybrid vehicle would rely mostly on fuel. It can also be noticed from the three experiments that more messages are needed to establish the connection than to update the SOC, even when fully charging the fleet. This can be explained by the fact that most messages are exchanged for the initial handshake where the vehicle is identified and authorized by the utility [10].



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how many cars will compose the fleet: 50
Energy threshold for EVs in kWh: 180
There are more messages for initialization than for SOC by 1302424839.148 bytes
The charging process will generate 60.304 kbps
>>
>>
how many cars will compose the fleet: 100
Energy threshold for EVs in kWh: 180
There are more messages for initialization than for SOC by 2604849849.656 bytes
The charging process will generate 120.608 kbps
The maximum speed of the system is 100 kbps
>>
>>
how many cars will compose the fleet: 150
Energy threshold for EVs in kWh: 180
The fleet will be partially charged at  9.837 percent, keep some fuel on your hybrid
There are more messages for initialization than for SOC by 3907458923.882 bytes
The charging process will generate 180.903 kbps
The maximum speed of the system is 100 kbps
>>
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Fig. 1: Results obtained from MATLAB.

V. CONCLUSIONS

This work briefly discusses the introduction of EVs into the smart cities environment and how they integrate with smart grids to provide V2G applications. Moreover, a fleet scenario was built together with a MATLAB script to calculate the communication data rate to charge a fleet based on the number of vehicles and the total of energy available for charging.

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