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A SIMULATION TOOL FOR EV CHARGING STATION DIMENSIONING

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Abstract. Most future users of electric vehicles (EVs) and plug-in hybrids (PHEVs) will be commuters below 40 miles round trip and will charge their cars at night in their own garages. However, in order for these vehicles to be widely used, an adequate infrastructure of charging stations is required. In this paper, we focus on in-road charging stations which are by far the most challenging in terms of dimensioning (as compared to e.g. stations located in parking lots of shopping centres).

In-road charging stations will be used mostly by EV drivers who occasionally travel distances higher than their vehicle range (PHEV drivers are not expected to use such stations). Although vehicle flow is not expected to be high, station dimensioning is by no means trivial, both in terms of space (number of outlets) and in terms of power requirement. We present a simulation tool that can help in dimensioning a charging station. A multipurpose station is considered, where quick-drop battery replacement systems may coexist with fast charging outlets and slow charging outlets (although the latter will be seldom used).

Our tool is based on Matlab [1] and offers relevant information like usage throughout the day, expected queues, etc. The results are displayed in graphical format for a better visualization and understanding.

Charging options for electric vehicles

Most EVs are capable of battery recharging at different speeds (the most common option is the use of more than one connector, with different standards). Battery swapping is another alternative to recharging, but only a few vehicles have adopted this system [2][3]. On the next paragraphs we will briefly describe all charging methods:

- Standard (or slow) charge: the plug provides 3.3kW (14 amperes at 240 volts). This is the system used for those who recharge their EVs at home, during the night. It is expected to be seldom used at on-road charging stations. As an example, a 24kWh battery (e.g. the battery pack of the Nissan Leaf [4]) takes more than 7 hours to be fully charged.
- Fast charge: there are different options, according to the type of current supplied (DC, AC, three-phase AC, etc.) and the available power levels. To mention only a few, the SAE J1772-2009 connector supplies 16.8 kW (70A at 240V, AC); the VDE-AR-E 2623-2-2 connector supplies 43.5 kW (63A at 400V, three-phase AC); and Level 3 charging stations [5] supply 62.5 kW (125A at 500V, DC). For example, charging a 24kWh battery pack to 80% of its capacity may take, with the previous options: 1 hour 10 minutes; 26 minutes; or 18 minutes. Figure 1 shows the connectors for each of these charging systems.
- Quick drop systems: instead of charging the battery, a robotized system replaces it with a fully charged one. The process may take less than one minute. However, there are important drawbacks: the cost of the system, the need for a normalization of batteries among the different manufacturers, etc.

An on-road charging station may need to include all possible recharging options, and its dimensioning is not an easy task, mainly because of the long time needed to recharge each vehicle.

Figure 1: Different charging standards and associated connectors. Left to right: SAE J1772-2009, VDE-AR-E 2623-2-2 and CHAdeMO (Level 3).

Simulation tool developed

We have developed a simulation tool that can help in charging station dimensioning. The tool has been developed in Matlab [1], but can be easily ported to other programming languages. In particular, the software is fully compatible with Octave [6], the most popular GNU alternative to Matlab.

The main input data required by the program is the expected vehicle flow during a standard day. With such data, the system simulates the behaviour of the station during several days, adding random deviations to vehicle flow. The most important output given by our system reflects the number of vehicles queued throughout the day.

Input data

Configuration of input data is entered as part of the Matlab code. Needed data includes the expected vehicle flow during the day, the expected percentages of fast/slow charges and quick drops; the time required for each service; and the number of places available per charging system. Figure 2 shows how these data are entered in the code (some repetitive lines have been omitted in order to improve readability).

```
% opening time: 6am
opening = 6;

% hours open: 18 (from 6:00 to 23:59)
hoursopen = 18;

% vehicle flow per hour while the charging station is open (6:00 to 23:59)
vflow(1) = 6; % 6:00 to 6:59
vflow(2) = 15; % 7:00 to 7:59
…
vflow(18) = 6; % 23:00 to 23:59

% mean percentage of each service
p_fast = 80;  % 90% fast charge (1:80)
p_drop = 99;  % 19% quick drop (81:99)
p_slow = 100; % 1% slow charge (99:100)

% time required for each service
t_fast = 30; % 30 minutes fast charge
t_slow = 360; % 360 minutes slow charge
t_drop = 5; % 5 minutes quick drop

% number of boxes per service
n_fast = 10; % 10 fast charge outlets
n_slow = 2; % 2 slow charge outlets
n_drop = 1; % 1 quick drop box
```
Figure 2: Input data for the system.

Simulation loop

The simulation loop performs, in first place, a random assignment of entering hours per vehicle. According to the expected vehicle flow per hour, a minute per minute description of the cars entering the charging station is obtained.

Using the previous information, a simulation of the time required to charge each vehicle is carried out, so that the number of vehicles present in the station can be updated every minute. The result is an instant picture of the charging station situation, which is stored for further analysis. Whenever the number of vehicles exceeds the number of available places, a queue is created. The frequency and size of these queues will permit dimensioning the station.

Finally, all results are also output as figures, in order to better understand the behaviour of the station.

Example of results

As an example, we will show some of the results obtained when the configuration data corresponds to the data shown in the previous figure 2. First, the vehicle flow we entered as input data is represented in the left plot of figure 3 (the peak hours are clearly shown). Then, the result of randomly selecting the entering hours per vehicle (for one of the runs of the simulation loop) is shown in the right plot. According to the results, up to 3 vehicles can enter the station in the same minute.

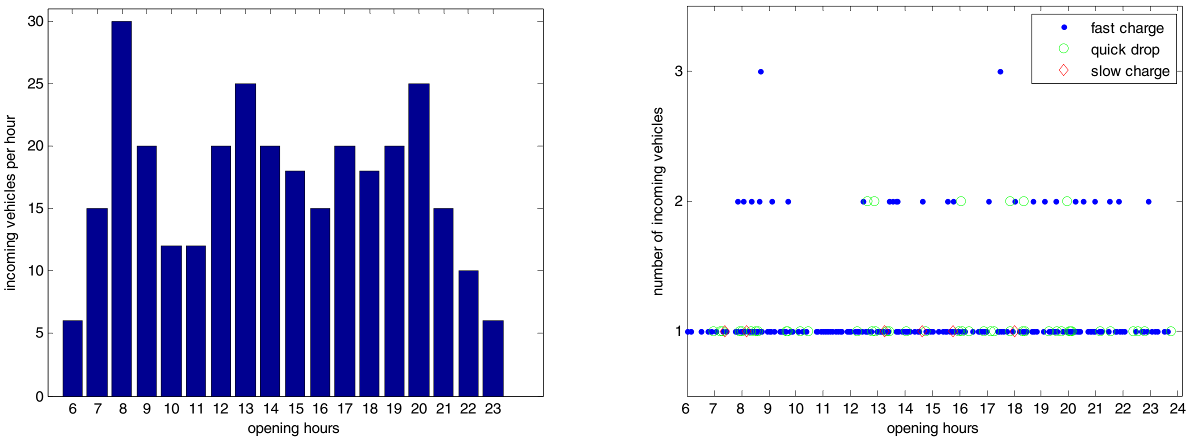

Figure 3: Vehicle flow per hour and simulation of incoming vehicles per minute.

Once the incoming vehicles per minute are computed, the system computes the number of vehicles that are in the station at every minute; and the queues (vehicles not attended, waiting for their turn). These results are shown in figure 4 (for one run of the simulation loop). According to these plots, during peak hours queues can reach up to 9 vehicles in the fast charging outlets; up to 2 vehicles in the quick drop boxes; and up to 2 vehicles in the slow charging outlets. However, this is only one of the runs of the simulation loop, which corresponds to one particular day. If we want to make sure about the maximum queues that can be expected, we can also plot the maximum values among multiple runs. In figure 5 we show as an example the maximum values obtained for the queues after 20 runs (the complete data in the left plot and a detail of the peak hours in the right plot).

Conclusion

Charging station dimensioning is not an easy task, mainly because charging times vary from vehicle to vehicle and may take long. A simulation tool like the one presented in this paper may help in this task by showing the expected results for a certain station setup.

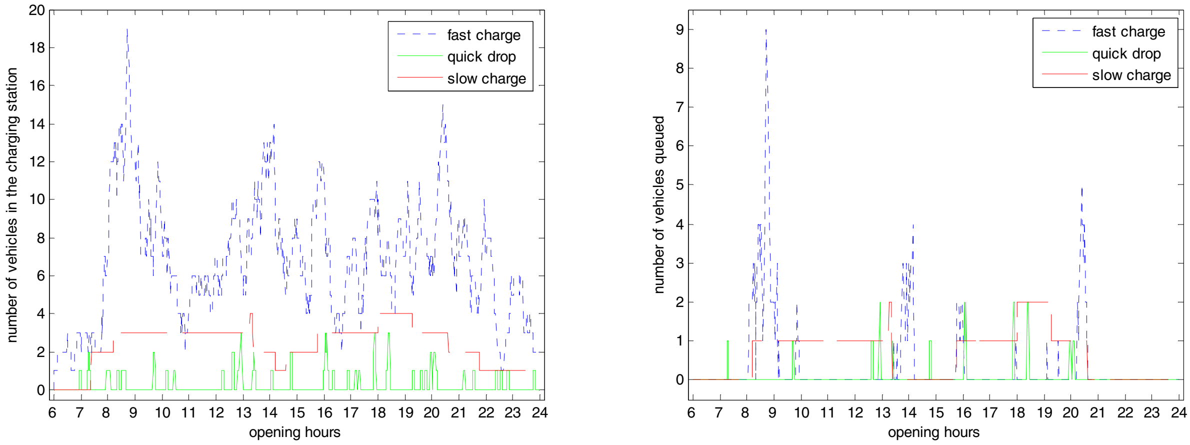

Figure 4: Vehicles in the station and vehicles queued, per minute.

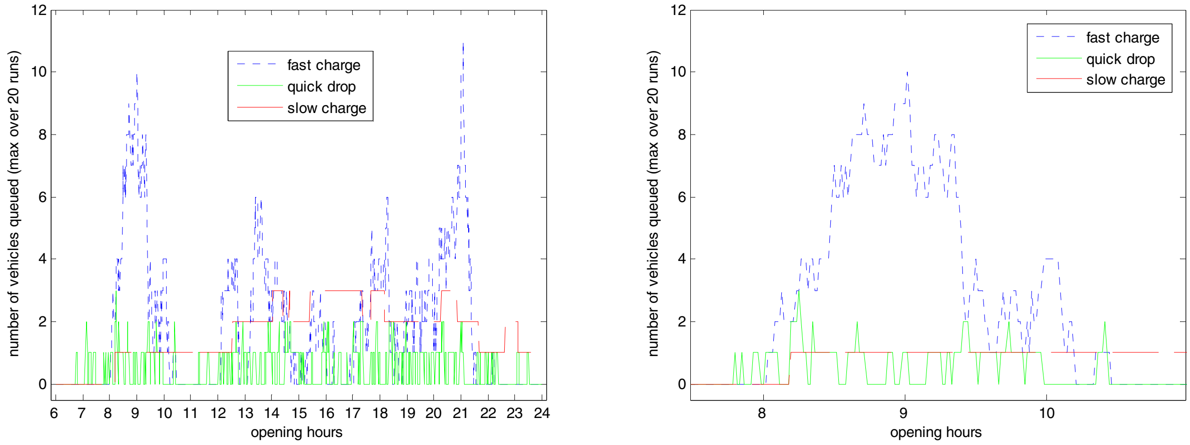

Figure 5: Maximum queue values after 20 runs of the simulation loop (20 days).

One of the most important results output by our system is the expected length of the queues. We show this result both as a vector (so that it can be further analysed) and as a figure, so that the most relevant peaks can be easily identified.

The tool is extremely easy to use, and a complete simulation for 20 days of charging station usage takes less than one second. It has been developed in Matlab, but it is fully compatible with Octave and easily portable to other programming languages.

References

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[2] Renault Quick-drop system, http://www.renault-ze.com.

[3] Tesla model S from tesla Motors. http://www.teslamotors.com/models.

[4] Nissan Leaf. http://www.nissan.es.

[5] BTCpower: electric vehicle chargers level 3. http://www.btcpower.com/products-and-applications/electric-vehicle-chargers-level-3.

[6] Octave, interpreted language for numerical computation. http://www.gnu.org/software/octave.