Power demand considerations at electric vehicle charging hubs.

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1 ABSTRACT

Charge profiles for a range of Battery Electric Vehicles (EV) were tested on chargers with an output power of 300kW. These charge profiles were then used in a model to show the power a charging hub might require at busy times. These results show that for a charging hub with 10 chargers there is little chance of requiring a grid connection of 3MW (10 x 300kW). There are business advantages to be exploited by understanding this information which could be used to reduce the cost of the infrastructure or to increase energy sales.

The data can also be used to show how there would be little or no impact to the customer in terms of charging time if a site is power limited when load is managed correctly.

2 INTRODUCTION

Worldwide sales of EV’s are increasing at a growing rate since their mainstream introduction in the early 2010’s. With a significant number of battery electric vehicles on the road the charging infrastructure needs to grow and supply the energy required. A proportion of this energy will come from ‘on the go’ fast charging sites like the ones bp is installing in the UK, Europe, Australia and the USA. Customers are looking to have an EV charging experience that is as close to the convenience of fossil fuels as possible on long journeys. bp aims to reduce the charging times for drivers by providing suitable charging infrastructure whilst creating a viable and efficient business. To build this infrastructure it is important to make data based decisions. This paper looks at the power requirements for a charging hub with 20 connectors on 10 charging units.

3 TESTING

3.1 Test Method

Two 300kW chargers located on a bp site in the UK were used for testing. The test vehicles were not selected, they were allowed to arrive randomly and charge as they normally would. Details of the vehicles were recorded and charging data was collected through the charger and server.

3.2 Controls

As a result of these tests being conducted on commercially relevant chargers installed outside, the ambient conditions were uncontrolled. Temperatures ranged from 1°C to 26°C and results were collected over a period of 9 months. The measurement accuracy of these chargers metering devices is covered by IEC 50470-1. This means the margin for error is under 1% on the metered energy.

3.3 Test selection

From this data a selection of charging profiles was then selected based on the starting State Of Charge (SOC) of the vehicles tested. Vehicle charge profiles were chosen with SOCs between 2 and 23% for the start of the charge event recorded. Where there was more than one profile available for a type of vehicle the highest peak power was selected. Tests were all vehicle limited so the data is a true representation of the demand rather than an internal limit of the charger. Vehicles with batteries between 32 and 85kWh of capacity and with claimed maximum charging powers between 46 and 233kW were chosen. Of the 10 vehicles selected from recorded data, two were 800V architecture and eight were 400V.

3.4 Claimed Power

Table 1. Claimed charging power vs measured.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Claimed Max charging power - (kW)</th>
<th>Measured Maximum Power (kW)</th>
<th>Achieved power vs claim (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>59.6</td>
<td>74.6</td>
</tr>
<tr>
<td>2</td>
<td>124</td>
<td>95.6</td>
<td>77.1</td>
</tr>
<tr>
<td>3</td>
<td>233</td>
<td>233.9</td>
<td>100.4</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>70.7</td>
<td>88.3</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
<td>81.9</td>
<td>66.0</td>
</tr>
<tr>
<td>6</td>
<td>112</td>
<td>79.3</td>
<td>70.8</td>
</tr>
<tr>
<td>7</td>
<td>210</td>
<td>134.3</td>
<td>64.0</td>
</tr>
<tr>
<td>8</td>
<td>135</td>
<td>88.7</td>
<td>65.7</td>
</tr>
<tr>
<td>9</td>
<td>223</td>
<td>99.7</td>
<td>44.7</td>
</tr>
<tr>
<td>10</td>
<td>49</td>
<td>48.2</td>
<td>98.3</td>
</tr>
<tr>
<td>Average</td>
<td>137</td>
<td>99.2</td>
<td>72.4</td>
</tr>
</tbody>
</table>
The data gathered showed there is a significant difference between claimed charging power and achieved charging power. This difference can cause frustration for customers, and they often believe any failure to achieve the specification is a result of the charger performance capability.

### 3.5 Instrumented test vehicle

One of the 800V vehicles used for testing was an instrumented test vehicle owned by bp so this was selected. This vehicle has been tested many times on many different chargers and is a 2022 registered vehicle with under 10,000 miles on the odometer. For this paper, data collected by the vehicle has been used from chargers rated at 175kW as well as 300kW. For all modeling work the profile with the highest peak power recorded was chosen.

### 4 CHARGE PROFILES

#### 4.1

Figure 1 shows the individual charge profiles recorded for the vehicles used in the simulation discussed in section 5. There is a variety of behaviour seen here from the different vehicles. The profiles display different control strategies employed by various OEMs. Vehicle 3 can be seen achieving the highest power but derates almost to zero, to control temperature. This is the instrumented vehicle mentioned in section 3.4. Many of the profiles display increasing power levels at some point in the first 25 minutes. This power rise is controlled by the Battery Management System (BMS) of the vehicle. It will depend on a range of factors including battery temperature, SOC and pack temperature gradients.

### 5 MODELING

#### 5.1 Simulated Charging Hub

A basic model was created to show change in total power requirement over time when all 20 connectors of the 10 chargers are utilised. Each 300kW charger has 2 connectors and each connector can deliver up to 300kW but not exceed 300kW total for both. A four minute offset was applied between the operation each charger to simulate different vehicle arrival times. Each of the 10 EV charge profiles used was applied twice and the pairs are time aligned. This means the peak of the highest power profile is doubled creating a more severe condition.

#### 5.2 Power demand:

Figure 2 shows the power that 20 modelled EVs would demand from the charging hub. A total theoretical maximum power that the chargers could deliver is 3MW. This simulation showed a maximum of 1610kW, or 54% of maximum was required to satisfy vehicle demand. If all 20 EVs peak power draw were to align then the demand would be 1983kW, or 66% of maximum.
5.3 Appropriate power levels

It would likely be appropriate to run a charging hub with 20 sockets at just over half the power theoretically required because the simulation shows this demand would satisfy vehicle power demand most of the time. In the modelling there is also no downtime between vehicles which creates a worst-case scenario. In reality, there would be connectors which not charging sometimes, even during busy periods.

As the number of connectors is reduced the power requirements per charger would increase. For example, the 2 connectors on 1 charger would use 94% of the rated power if the highest and lowest power vehicles were charging simultaneously. This is not an unusual event and would be very likely to occur. However, having 10 of the highest charge rate vehicles and 10 others all arriving at a hub with 20 connectors and the peak power section of the charge events aligning is unlikely.

5.4 Future proofing

Chargers are expected to operate for 10 years in the field. This gives a time window where there needs to be confidence the infrastructure is suitable for the demands of the evolving vehicle parc.

Data on upcoming vehicles was taken from an online source [1] and combined with the charging profile of the highest performing vehicle to create a scaled prediction of how this scenario would look with a car parc of vehicles averaging 167kW of peak charging power demand as shown in Figure 3. This 167kW average power is 30kW higher than the average for the vehicle charge profiles used in the first model. It also assumes the vehicles achieve 100% their claimed peak power in the near future unlike the 72.4% average achieved in the first model. As before, a 4 minute arrival interval was applied in the same way. This resulted in the maximum power demand being 2294kW - over 700kW lower than the maximum for this charging hub despite the potential total demand from these future vehicles being 3.35MW.

5.5 Load management

Load Management Systems (LMS) are already available to distribute load between chargers and protect incoming power supplies. If configured well a system can be used to share the load intelligently and minimise impact on customer experience. One limitation of a LMS is built into the charger hardware. There is usually a number of DC converters and each one of these has to be dedicated to one vehicle. A 300kW, dual connector, charger for example could be made up with 4 x 75kW converters. If 1 car is demanding 80kW it would be taking up 2 of the 4 units, leaving only 150kW output available for a second vehicle. It may be better for customer experience overall to limit the first vehicle to 75kW on 1 and make 225kW available to a second vehicle if required.

For safety reasons it would be essential to run a Load Management System at any hub where total charger power could exceed feed capability.

5.6 Peak charging rate vs 75% power

Allowing a vehicle to charge at its maximum demanded power is not necessarily a significantly quicker way to achieve a target SOC. From the significant number of tests conducted with the instrumented 800V vehicle it has become clear that cell temperature-based derating can cause such significant drops in demanded power that a target SOC of over 80% could be more quickly achieved with a lower power. This can be seen in Figure 1 where vehicle 3 is by far the highest power consumption vehicle but after 20 minutes it derates below 10kW as can be seen in the low power portion of Vehicle 3 charge profile in Figure 1.
Figure 4 shows the cumulative energy supplied to the instrumented vehicle with 2 different peak power levels. The high power charge achieves the vehicles maximum rated power and provides 10 – 80% charge 263 seconds earlier than the 173kW maximum charge.

The derate lasts for 184 seconds and stays below 10kW for the full duration allowing the vehicle with the lower rate charge to catch up. At the time the 233kW event resumes, the 173kW event is only 3% behind.

As the 233kW event achieves 80% the 173kW charge is 300 seconds (5 minutes) behind but by the end of the derate period it was only 79 (1 minute 20 seconds) seconds behind.

6 CONCLUSIONS

This study has described the impact of vehicle charging performance on power demand from an electric vehicle charging forecourt based on the measured charging profiles of a sample of vehicles taken from those arriving at the hub.

High utilisation of hardware improves the business case for the charging site and allows more competitive rates to be provided to the customer.

For electric vehicle owners charging at public DC charging stations it is likely that failing to achieve the maximum power could, in some cases, not result in customer dissatisfaction. Understanding the needs of the customer in advance could be key to providing the best service. For example, knowing that Car A is staying for 45 minutes for its occupants to have lunch and Car B wants to get away as soon as it hits 70% could be used to inform how power is distributed within both the forecourt network and each charging unit. This would potentially improve the experience for occupants of Car B without any negative impact on the timing for charging Car A. Potentially Car A would even get a marginal improvement on battery life [2]. This customer requirement data could be collected on screen or via an app. Informing customers when the limiting factor is their car rather than the charger would also be beneficial for the perception of the charging network.

7 FURTHER WORK

Sensitivity analysis would be worth conducting to see how higher and lower numbers of connectors at a hub affect the grid power connection required.

Most of the testing done was conducted at temperatures below 15°C therefore it would be worthwhile to continue data collection and repeat modelling in warmer weather.

It would be useful to conduct further work on the 800V vehicle to look at different charger power limits, for example 150, 200, 210kW to identify optimum power levels for achieving different target SOC levels and ideally conduct the same with other vehicles to identify if there is there a sweet spot for this and other vehicles.

Comparison to real world data for a charge hub location like this would be desirable for validation and improvement of this work.

8 ACRONYMS

SOC: State of Charge
LMS: Load Management System
BMS: Battery Management System
EV: Battery Electric Vehicles

9 REFERENCES AND BIBLIOGRAPHY

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10 CONTACT

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