Electric cars: Technology
Lecture notes: Lecture 4.3

Battery swap

The battery swap works on the basis of switching out the depleted battery and replacing the same with a full battery. The process involves driving into a battery switching bay, and an automated process will position the vehicle, switch out the current battery and replace it with a fully charged battery. The depleted batteries are charged in the station for later deployment.

Advantages

- Battery swap can provide a new fully charged battery, without the need to wait for the charging duration. In this case, the range anxiety is eased, and to some extent, infinite mileage is obtained.
- Batteries are charged outside the vehicles, so there is no limitation on the size, weight and power levels of the charger.
- Batteries are left being charged in battery swap station, which provides high flexibility on the charging power as well as charging time. Batteries can be charged according to the local load and renewable energy generation.

Challenges

1. Requirement of Standardized Battery Interface across multiple car manufacturers. This would mean that car manufacturers who would like to differentiate based on innovative battery technology will have to share that advantage. The battery pack for an average passenger car will weigh 250 to 300 kg. To provide good weight distribution and thus safe handling of the car, the battery pack could be specifically designed for that vehicle and therefore

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integrated into the structure. This will make standardization difficult.

2. Consumer acceptance of not owning a battery and having to change the vehicle battery. The consumer would be wary of switching to a battery which he/she is unsure of with respect to its state of health.
3. The battery state of health estimation - To monetize the battery usage, there should be a fool proof way to estimate the batteries state of health to check for its usage pattern.
4. Safety Perspective - The electrical connection between the battery and the vehicle carries a very high current, and it is this connection that would need to be made and broken each time the battery is exchanged. At best, it will cause wear and degradation at the key link between the two components, at worst; it has the potential to cause a massive discharge, with all the consequences that might ensue.

Quick Charge Replenishment (QCR) Comparison: Fast charging Vs battery swap

- First, we looked at the at the number of visits. In order to get the car charged with fast charging, or to replace your car's battery with battery swap, one needs to go to a charging station. Based on the data from the Dutch EV mobility survey of 2009, we saw that the average number of visits is always lower for the battery swap compared to fast charging. This is because more energy is transferred per battery swap compared to fast charging. Also, a battery can be fast charged only upto 75-85% state of charge and beyond that the charging power is limited. On the contrary, you always leave the

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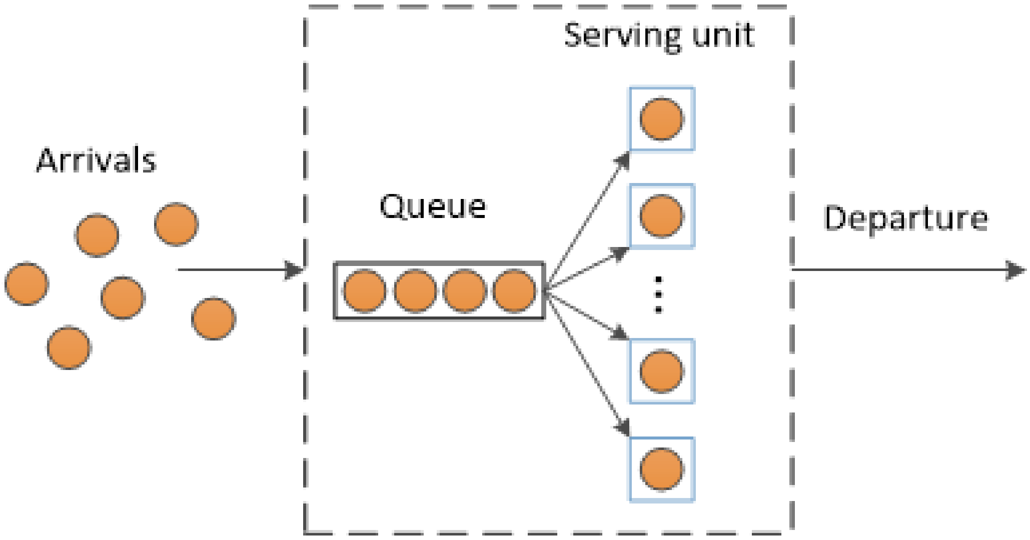
battery swap station with a full battery with 100% state of charge.

- Fast charging provides a charging power normally higher than or equal to 50kW, and it may cause a severe impact on the grid especially when it's peak time when multiple cars are charging. On the contrary, the charging processes at a battery swap station can be shifted in time and can be controlled.
- In terms of service time, fast charging requires different time duration depending on the charging power, the capacity of the battery whether the battery has to be partially or fully charged whereas in battery swap, it's the only process time involved in replacing a battery.

Queuing theory



Queuing theory is used to compare the operation of a battery swap and fast charging station. The key factors considered that can influence the operation of battery swap and fast charging are:

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1. The arrival of customers: This includes the distribution of the arrival times and the time interval in between.
2. The behavior of customers: For example, are the customers willing to wait or leave after a short time?
3. The service times: In this case, it is the charging time for the fast charging and the time for the battery replacement.
4. The service discipline: There are many possibilities of service discipline like first come-first served, random order, last come first served, priorities, etc. Usually, we consider first come-first served order for this analysis.
5. The number of service units: This is the number of fast charging points/ battery swap lanes.
6. Waiting room. There can be limitations concerning the total number of customers that can be served. The arriving customers could be rejected if both the serving capacity and the queue are full. In the case of electric cars, the total amount of parking spaces can be considered as the waiting room.

Waiting time

According to the queuing theory, the average waiting time per customer can be seen as a function of the number of serving units for a certain EV range.

- Case 1: Fast Charging-Absolute Worst Case: It represents charging the battery from the minimum driving reserved range SOC, which is an equivalent 10km range, to 80% SOC.
- Case 2: Fast Charging-Average Peak Case: It represents fast charging the car in the evening peak based on driving energy needs.
- Case 3: Battery swap

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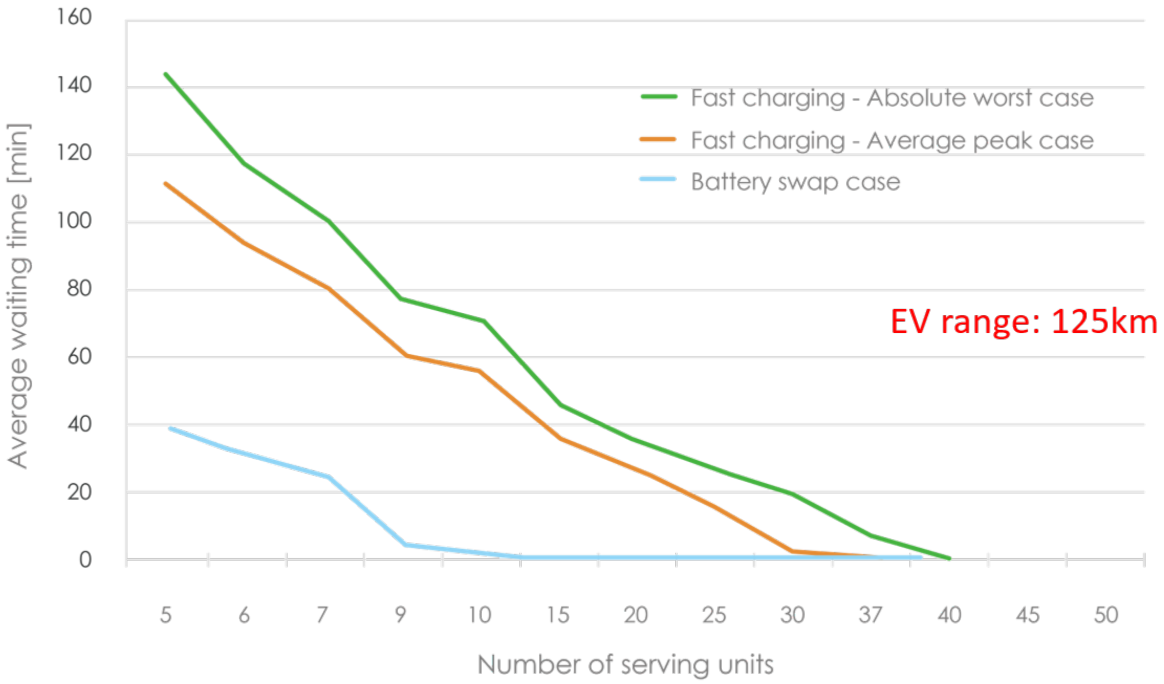

We looked at the optimum number of serving units in a quick charge station versus vehicle range with 10 minutes considered as the acceptable waiting time in the queue.

- From this picture we can see the decreasing trend in the number of serving units required as vehicle range increases. However, the decreasing trend is significantly different for each of the three cases of charging technology and strategy.
- Vehicles with higher range need less number of visits per year to quick-charge station, and it decreases the arrival rate per station. So lower number of serving units can handle the charging needs.
- For the fast charging - Average Peak Case, significantly lower number of serving units are required. This is because the charging energy and charging time for the Average Peak Case is always lower than that of the Absolute Worst Case. Therefore, one serving unit and subsequently the whole station

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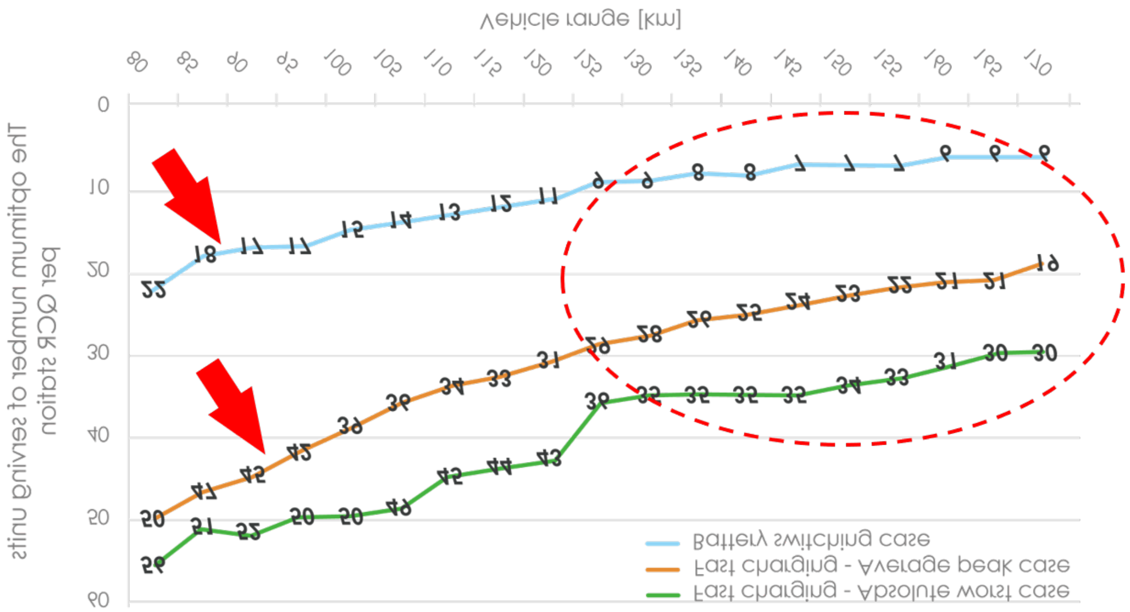
can serve more cars in a certain time. This means that the whole station can handle the same traffic behaviour with a lower number of serving units.

- Finally, only about one-third of the serving units is needed for Battery Switching Case. Since the serving time is significantly lower for battery swap, which is about 5 min, the same traffic can be handled with less number of serving units at the battery swap station.



Extra batteries required

Another key factor to be considered for battery swap is the extra number of batteries required for satisfying the travel profile. For a battery swap scenario, batteries are required on-board the vehicle for driving and extra batteries are needed at the station for charging and to be kept ready for a swap. On the contrary, fast charging does not require extra batteries. In the research for the Dutch scenario, it was assumed that 10 minutes is the average waiting time in the queue, the charging power in the swap station is 10.8kW, and each simulation for battery swap was started with 80 percent extra batteries.

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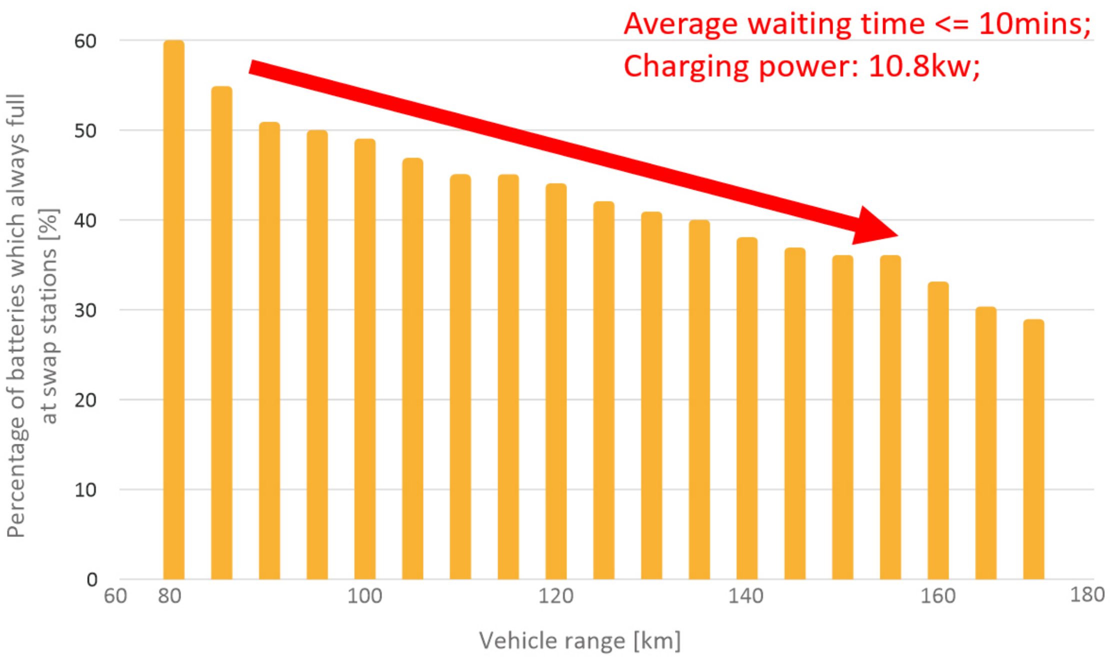

- This graph shows the number of batteries that have always been fully charged and ready to be swapped at the battery swap station as a function of EV range. Depending on the arrival rate of the EVs, these “always fully charged batteries” can be considered excessive and part of them are not necessary. From this graph, it can be seen that for an EV fleet with higher range and larger battery capacity, a lesser number of fully charged batteries are ready at the swap station as the batteries with higher capacity need longer time to be re-charged to full.
- Then, the percentage of batteries that are waiting for charge or in charging process versus EV range in the swap station is shown in this purple curve. This is simply calculated by 80%, the simulation point, minus the number of batteries that are always fully charged, which is the orange bars. This indicates that more minimum overall extra batteries are required in the battery swap station if the EVs have higher range.

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Example of battery swap: Betterplace and Tesla

Betterplace was one of the first companies in the world to demonstrate and offer battery swap technology commercially using a Renault Fluence Z.E. The battery swap was done is about 1 min and offered a full recharged 22 kWh battery pack to the car that can provide about 100 mile range. To understand how the battery swap was done, you can look at the video below from youtube.

https://www.youtube.com/watch?v=OHHvjsFm_88

Currently, Tesla offers the possibility to do battery swap using the Tesla Model S. In this demonstration video, we can see how a Tesla car battery is swapped in the same time that it takes to refuel a combustion engine car.

https://www.youtube.com/watch?v=S0-sHtlCZ7M

References

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X. Tan, B. Sun and D. H. K. Tsang, *Queueing network models for electric vehicle charging station with battery swapping*, IEEE Conference on Smart Grid Communications , Venice, 2014, pp. 1-6. This paper is copyrighted by IEEE and can be accessed from IEEE xplore.

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