Electric Vehicle Battery Swapping Station

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Outline

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  - EV owner perspective
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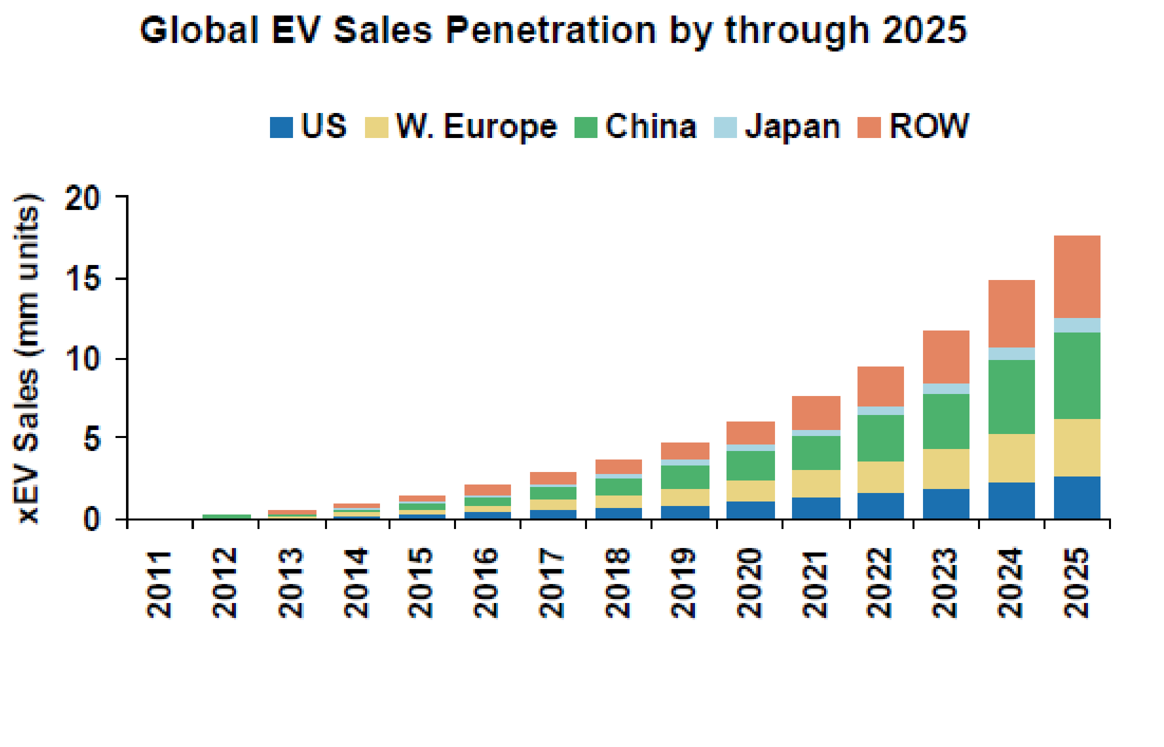
Introduction

- The development of electric vehicles (EVs) is widely favoured by a larger and growing segment of car owners, manufacturers, governments, municipalities and investors.
- It is anticipated that EVs will take 25% of the automotive market by 2020.



Source: Company data, FactSet, Morgan Stanley Researc

Introduction- cont'd

- Growing penetration of EVs can potentially reduce emission, save fuel cost for EV owners, and reduce the consumption of gasoline.
- It can also increase utilization of renewable energy such as wind and solar resources, as the EV's battery has the storage ability which can be potentially employed as a flexible source for intermittent energy resources.

Source: www.dreamstime.com

EV battery charging methods

- Plugging method (Individual outlets or Battery Charging Station (BCS))

Source: TESLA Motors

- Battery Swapping method

Source: www.medium.com

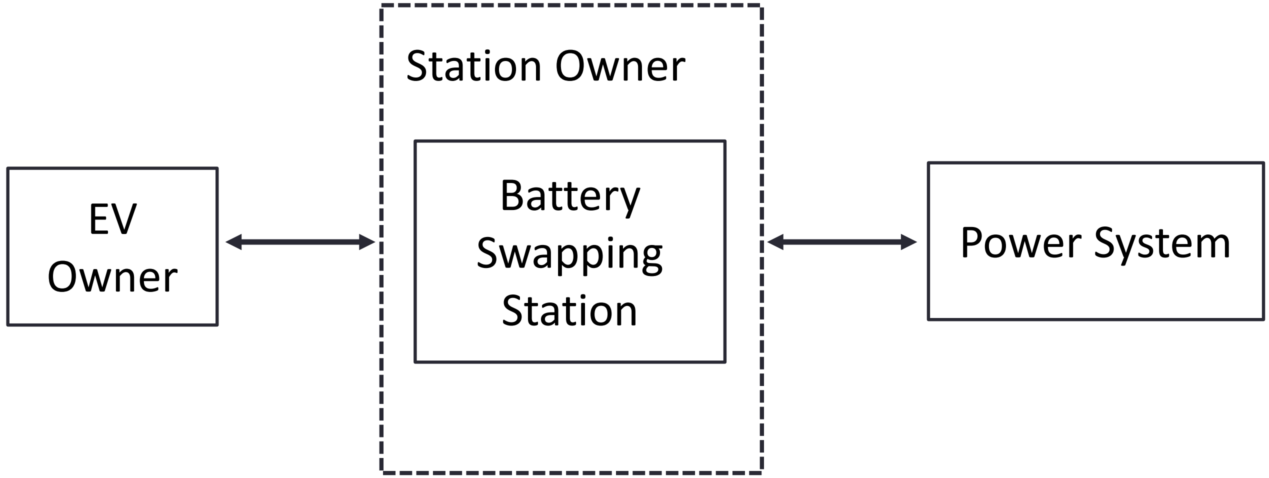
Comparison between the charging methods

- **Plugging method**
  - Takes much longer than fuelling a gasoline-powered vehicle and presents a barrier to EV adoption.
  - The cost of building charging facilities and the required real estate.
  - Battery lifetime.

- **Battery swapping method**
  - EV owners can easily pull over in a swapping station where an empty battery is automatically switched with a fully-charged one.
  - Just takes a few minutes to replace a battery.
  - By determining the optimal locations of BSS, drivers not only could charge their EVs as fast and easy as refuelling in a gas station, but also could extend their travel distances.
  - The price of the EVs dramatically drops, as the cost of the battery is deducted from the total vehicle cost.

BSS players

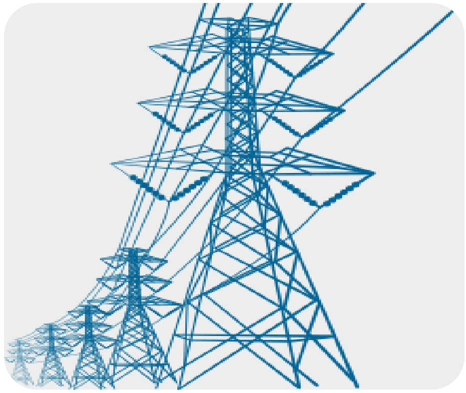
- BSS approach necessitates mutual interactions with all players involved, including but not limited to the EV owner, the station owner, and the power system.



BSS benefits- cont’d

Power system perspective

- Offers a controlled charging strategy.
- The BSS is able to postpone the charging of batteries to the night time or off-peak hours to avoid peak load and network congestion.
- The BSS can be treated as a large flexible load. By controlling the charging and discharging time of the batteries, the potential peak demand or overloading, caused by increasing penetration of EVs, can be flattened.
- It can be achieved by determining an intelligent charging schedule without the need of upgrading the current grid infrastructure.



Source: www.electricityindustrynl.ca

BSS benefits- cont’d

EV owner perspective

- Reducing the sticker price of EVs, as the station owns the batteries.
- Speeding up the battery charging, which would become as fast as refuelling a gasoline-powered vehicle.
- Allowing longer trip distance for the EV owners by accessing the fast battery swapping in the BSS.
- Relieving the concern of battery lifetime as the BSS operator runs healthy and advanced control strategy for battery charging to avoid sequential damages.
- Decreasing the cost of upgrading household infrastructure to high power chargers.

BSS benefits-cont'd

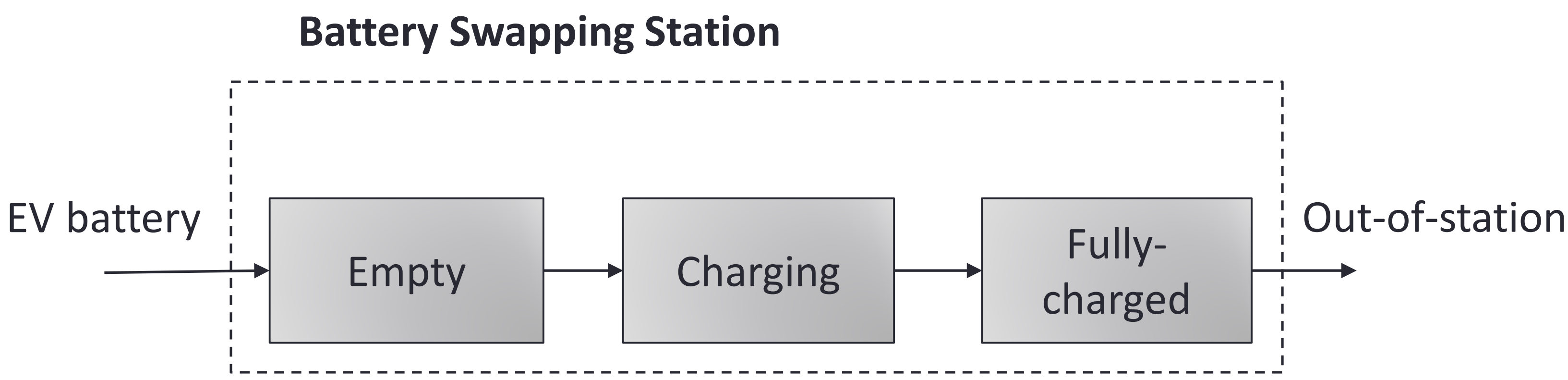
Station owner perspective

- Minimizing its electricity cost by scheduling the battery charging process.
- Maximizing its profit by participating in electricity markets and also providing ancillary services, such as demand response and spinning reserve.
- Reducing the cost of real estate, as there is no need to access large parking spaces.
- Offering convenience for charging the batteries due to the availability of consistent battery standards.

Source: http://www.mpxreview.com

BSS scheduling model

- The proposed model aims at scheduling the battery charging with respect to the availability of battery chargers, and hourly demand for swapping the batteries.
- Four different states are considered for each battery: empty, charging, fully-charged, and out-of-station.



BSS scheduling model- cont'd

- At each hour, every individual battery transits among these four states.
- As each battery enters the station, its state is toggled in a sequential order.
- When an empty battery is delivered from an EV owner, it will be put under the empty state.
- Once there is an empty slot to move this battery forward, the charging will start, empty state will become zero, and accordingly charging state will be one.
- When the battery is fully-charged, it will be moved to the next state, i.e., fully-charged state become one. A battery in the fully-charged state is ready to be swapped.
- By handing over the fully-charged battery to the EV owner, the battery is going out of the station, and consequently out-of-station state will become one, while other states will be zero.

BSS scheduling model- cont'd

- Number of batteries owned by BSS.
  - the total number of batteries, associated with the BSS, is a constant, represented by N^S. In other words, the station owner possesses this number of batteries to provide the swapping service to EV owners.
- Battery charger limit
  - The maximum number of batteries that can be charged simultaneously is limited by the number of charger in BSS (N^C).
- To ensure that the hourly demand is met, the total number of fully-charged batteries should be greater than the demand at each hour.
- Physical constraints in charging the batteries, including the minimum charging time, minimum/maximum charging rates, state of charge limits, etc.

Illustrative example

- A small BSS with 12 batteries.
- The BSS owns 4 battery chargers.
- Each empty battery needs to be charged for 6 hours to be fully-charged.
- It is assumed that there is no power limit on the BSS, i.e., 4 batteries can be charged at the same time, equivalent to the number of available chargers.
- The BSS schedule is studied for a 24-h horizon.

Illustrative example - cont'd

		Horus (1-24)																							
Batteries	B1	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	O	O	O	O	O	O
	B2	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	O	O	O	O
	B3	E	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	F	O	O
	B4	F	O	O	O	O	O	O	O	O	O	E	E	C	C	C	C	C	C	F	F	F	F	F	F
	B5	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C	C	C	C	F	F	F	F	F
	B6	C	C	C	C	F	F	O	O	O	O	O	O	O	O	E	E	C	C	C	C	C	C	F	F
	B7	C	C	C	C	C	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C	C	C
	B8	C	C	C	C	C	C	F	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C
	B9	C	C	C	C	C	C	F	F	F	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C
	B10	O	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	F	F	F
	B11	O	O	O	O	E	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F
	B12	O	O	O	O	O	O	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F

- Each battery can have one of these four states at every hour: empty (E), charging (C), fully-charged (F), and out-of-station (O).

Illustrative example - cont'd

		Horus (1-24)																							
Batteries	B1	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	O	O	O	O	O	O
	B2	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	O	O	O	O
	B3	E	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	F	O	O
	B4	F	O	O	O	O	O	O	O	O	O	E	E	C	C	C	C	C	C	F	F	F	F	F	F
	B5	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C	C	C	C	F	F	F	F	F
	B6	C	C	C	C	F	F	O	O	O	O	O	O	O	O	E	E	C	C	C	C	C	C	F	F
	B7	C	C	C	C	C	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C	C	C
	B8	C	C	C	C	C	C	F	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C	C	C
	B9	C	C	C	C	C	C	F	F	F	F	F	F	F	F	O	O	O	O	O	O	O	O	E	C
	B10	O	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	F	F	F
	B11	O	O	O	O	E	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F	F
	B12	O	O	O	O	O	O	E	E	E	E	E	C	C	C	C	C	C	F	F	F	F	F	F	F

Battery B1 remains empty for the first four hours, and once one of the battery chargers becomes available, it starts charging. For the next six hours, the battery is charging until being fully-charged. This battery stays at fully-charged state because of lack of demand. At hour 19, battery B1 is swapped with battery B7

Illustrative example - cont’d

- This illustrative example shows how the BSS can schedule battery charging in a way that:
  - (a) constraints associated with number of chargers is closely followed.
  - (b) there is always a fully-charged battery in the station, so as to serve customers in no time.
  - (c) each battery is closely tracked, so the lifetime/degradation can be accurately determined.
  - (d) it is possible that a battery stays in the station for most of the day (like B3) which is fine.

Conclusion

- The timely and viable idea of a BSS was introduced to supply power to EVs.
- Various involved players, such as the power system, the EV owner and the station owner, reap the benefits of the BSS.
- The advantages of the BSS deployment were enumerated from the perspectives of these three mentioned players.
- From the station owner's view, a BSS scheduling model was proposed in order to charge batteries in a sequential order, while taking into account various prevailing constraints.
- An illustrative example was provided on a small test BSS to showcase how the proposed model would perform.

Thank you

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