Battery Buffered Opportunity Charging

Enabling Fast, Opportunity Charging together with smaller, lower cost grid connections

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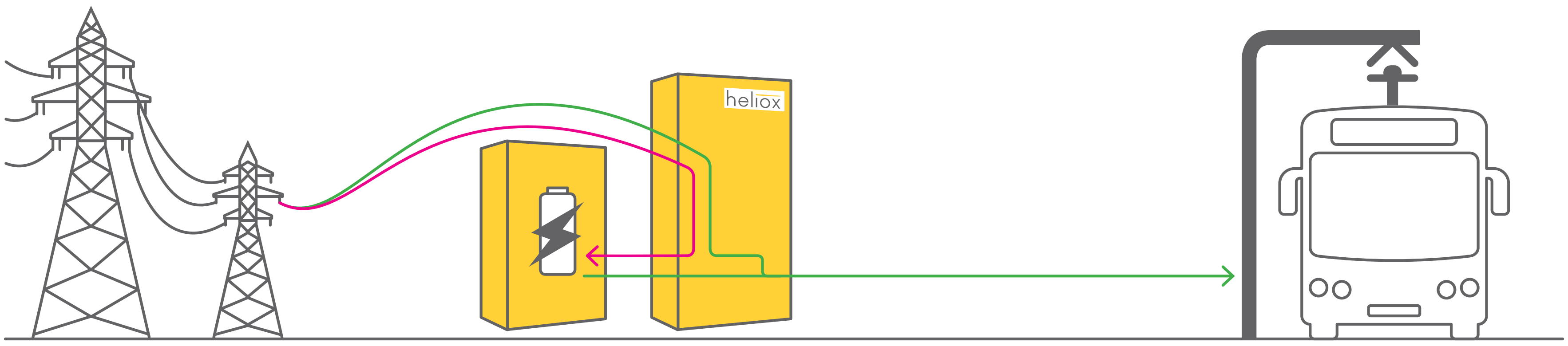
Advantages of Battery Buffered Opportunity Charging

- Save Grid Connection Costs
- Easier to install connections
- Smaller
- Store your own Solar
- Smart Grid



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Introduction

Battery electric vehicles have enormous potential to provide quiet, low emission transport at lower cost than diesel. The infrastructure costs and high peak demands on the electricity grid can make fast opportunity charging difficult to implement quickly and cost effectively. Using Battery buffering you can substantially reduce the electricity costs and potentially speed the implementation. By exploring why opportunity charging is beneficial, and how electricity is billed, we can understand the value of battery buffered opportunity charging.

Battery Buffering

Battery buffered opportunity charging adds a stationary battery to the charger. The battery can deliver a much higher peak power charging sprints than the grid connection can support, allowing a smaller, cheaper grid connection. While the opportunity charger is not being used when the battery is refilled, allowing it to draw a more constant, lower, power from the grid. Battery Buffering can save considerable electricity costs and enable future revenue streams from smart grid integration.

Understanding your Electricity Bill

Battery electric vehicles have enormous potential to provide quiet, low emission transport at lower cost than diesel. The infrastructure costs and high peak demands on the electricity grid can make fast opportunity charging difficult to implement quickly and cost effectively.

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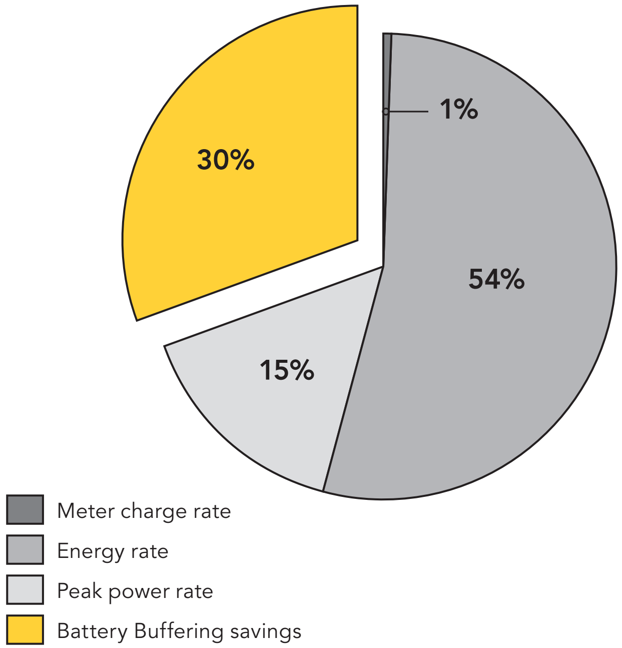
In Europe the power grid operation and the energy production are often handled by separate companies. The Meter Charge Rate and Power Rate will often be paid to your Distribution System Operator who runs the power grid, and the Energy Rate will be paid to your energy provider, possibly with a small per kWh surcharge to the distribution system operator.

Breakdown of Typical Opportunity Charging Electricity Costs



45% of your Electricity bill could be Peak Power charges for capacity you only use 17% of the time!

Energy Bill & Power Bill?

The example below helps to explain what a typical electricity bill for an opportunity charger looks like.

Monthly Electricity Bill for a 450kW Opportunity Charger, delivering 3, 5-minute charging sessions per hour between 6am and 10pm.

Item	Price	Quantity	Monthly Total *without* battery buffering	Monthly Total *with* battery buffering	*Explanation*
Meter Charge Rate	$4.59 per day	30 days	**$137.70**	**$137.70**	This is the charge for simply having a connection, it will usually be fixed by the size of the meter.
Energy Rate	$0.17608 per kWh	56 400 kWh	**$9,930.91**	**$9,930.91**	This is the rate charged for the energy used. The more energy you use to charge the vehicles, the higher this will be. Most utilities offer time of use rates where the energy is more expensive for example during peak use during the day; then cheaper at night. In some places you can work with an energy trading company to get rates which vary hourly based on market prices.
Peak Power (or Demand) Rate	$18.80 per kW	450kW	**$8,460.00**	**$2,820.00**	This fee is based on the highest peak power the meter records. If this were water plumbing, this would be the fastest flow rate the water is used at, compared to energy which is how many liters. This is important for the electricity distribution system operator since they need to size their equipment based on the highest electricity power you demand. Some distribution companies will separate this into your maximum contracted peak you agree to pay up front and they use to size the lines and transformers, and the maximum peak they measure.
Battery Buffering		*– 300kW*	**– $5,640.00**		
Total			**$18,528.61**	**$12.888.61**	The total – remember this is providing the energy for your fleet to drive 37,000km!

How Battery Buffering Cuts your Electricity Bill

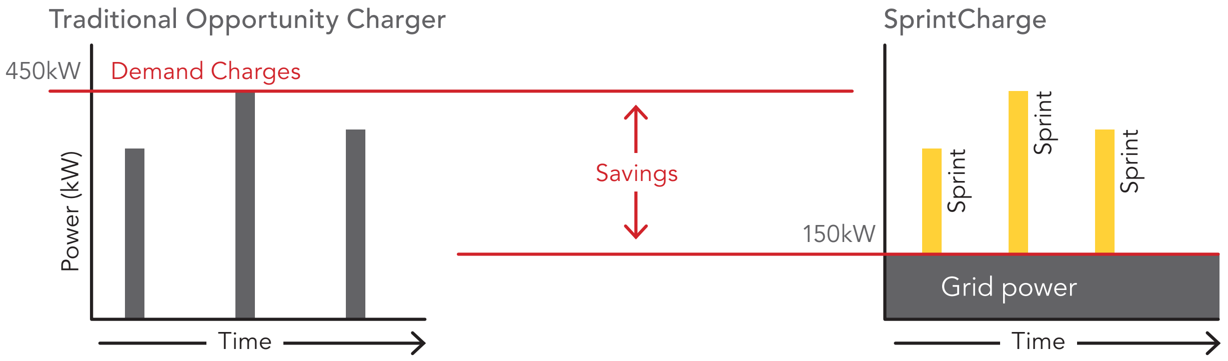
Battery buffering allows you to opportunity charge more cost effectively. **Adding a battery to an opportunity charger allows you to draw a continuous, low, average power from the grid and storing the energy in a battery.** Then using the energy to charge in sprints at high power for the brief intervals required. For example, you can draw a continuous 150kW from the grid, with a lower peak demand cost, then deliver fast opportunity charging at 450kW. This way, your peak demand will never exceed 150kW and your electricity bill will be predictable.

A smaller electrical grid connection can save you both capital and operational costs.

- Monthly demand charges in the above case it could save $5 640/mo. in peak demand charges.

- Smaller grid connections are also cheaper to install reducing your installation costs. High power electrical grid connections are often difficult to arrange and can take years to plan and install. Often local medium voltage distribution circuits of about 10MW are installed for a neighborhood.

Grid Power Comparison between Traditional Opportunity Chargers and SprintCharge



If adding traditional opportunity chargers would push the local distribution cable over its designed size, the utility may need to add a new line from the nearest high voltage substation at considerable delay and expense. If using battery buffering can avoid requiring a major utility upgrade, it could save considerable time and money.

- Smaller grid connections can be faster and easier to install, allowing more flexibility to put chargers at locations where they are most effective instead of where large grid connections are available.
- Battery buffer systems can be physically smaller than traditional opportunity chargers for a similar output power saving you valuable urban real estate.
- Opportunity to earn money from smart grid services (see page 17).
- If you have your own solar or other on-site generation, you can save the energy and avoid the low repayment rates from the grid.

On the next page, we will explain in more detail how this really works.

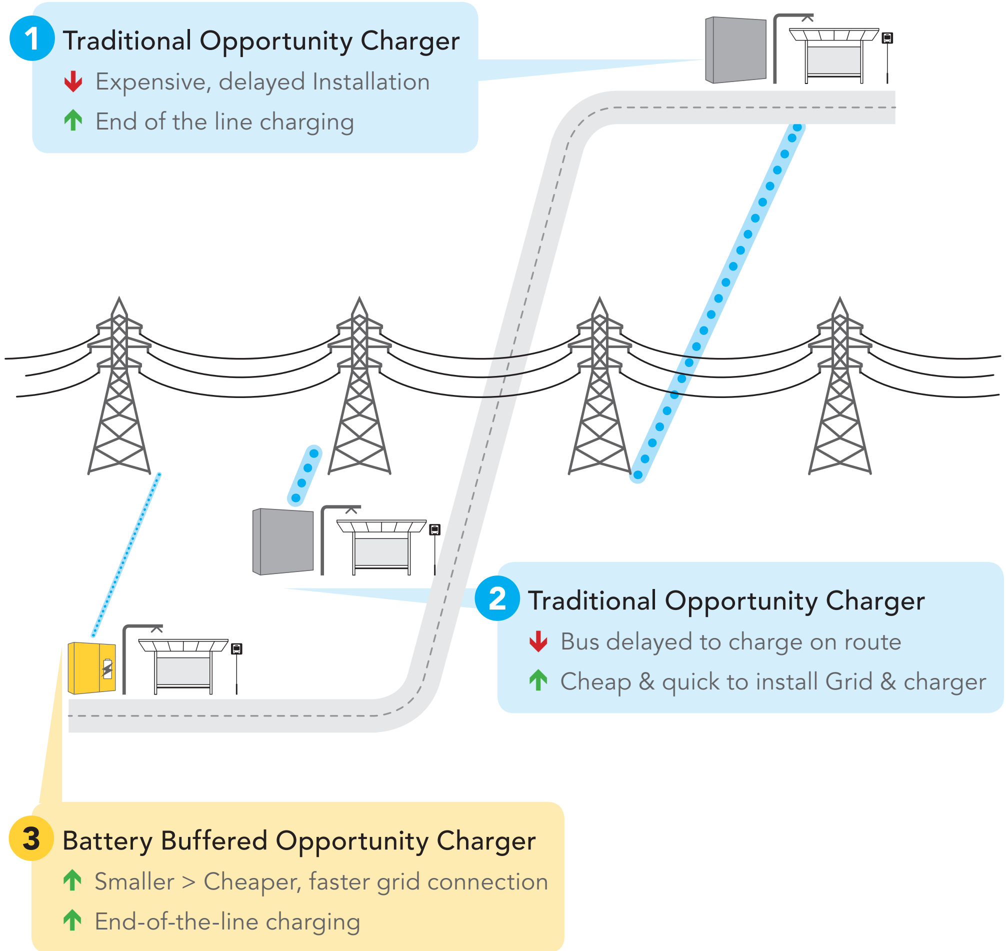
Route Planning Advantages of Battery Buffering

Battery buffering can allow you more flexibility in route planning, but letting you put chargers where your routes need it, rather than where you can find the grid connections you need.

1. Opportunity charging is often installed at the end-of-line where buses need to stop for several minutes for operator rest. If this is a remote location, it may require a large, expensive grid connection to be run from the nearest existing substation or distribution line.

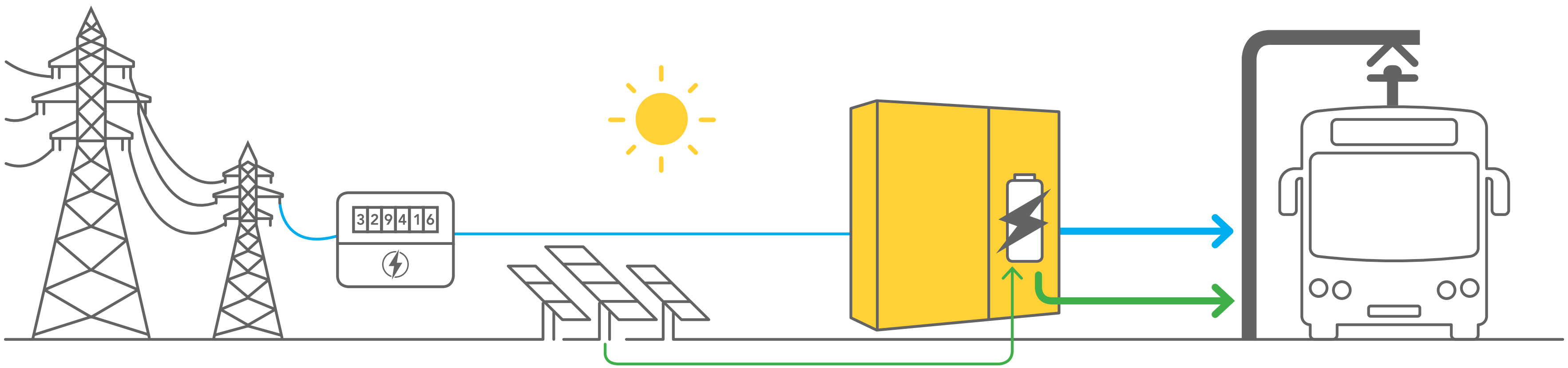
2. Installing opportunity chargers near available grid connections may save installation costs and time. However if the locations demand routes detour or force en-route stops it impacts customer experience.

3. Battery Buffering requires a smaller grid connection, and thus more flexible locations. This lets you charge where it makes most sense for your routes and your customers, with lower grid costs.



Savings Combined with Solar or other alternative on-site generation

Battery buffering can also make more efficient use of your solar panels or other on-site alternative energy sources. If you have extra solar power available during the day, beyond what you need to charge your vehicles, then you can usually sell that energy to the grid. The utility will usually pay you for the extra energy you give them, but usually at a lower price then they bill you when they sell energy to you. Using a battery system, you can store that extra solar energy on your own facility and use it to help charge without any costs from the utility.



Designing Battery Buffered Opportunity Chargers

In evaluating battery buffer systems, you need to consider the input power, output power and battery size.

Output power

The easiest to start with is the output power. Usually you want to charge the vehicles at the maximum possible rate so you can get the shortest possible charge times. 450kW is typical to get the vehicles and drivers back to work earning money as fast as possible.

Input power

Next, consider how long and how often the vehicles will need charging. This is driven by your route structure, how frequently there will be a vehicle to charge, and how long those charge sessions take. The combination will give you your average power, this is the minimum power and smallest grid connection that is possible for your application. If the minimum power is near the charging power, then battery buffering won't provide many benefits. These are minimum calculations and slightly larger connections may be better for flexibility and future proofing if schedules change.

(Number of buses Per Hour) x (Bus Charging Power) x (Charging Time) = (Minimum grid connection)

for example:

(3 buses per hour) x (450kW) x (5min ➔5/60min charging time) = 112.5kW Minimum grid connection

Battery size

The battery size is driven by a few factors. The battery needs to store enough energy to deliver opportunity charges for the longest expected duration. For example, if you foresee a need to charge 3 buses for 7min each (even on a once a year bad day), immediately after each other, the battery needs to store enough energy for that. The battery power is added to the grid power, so with a 150kW grid connection and 450kW, charging the batteries need to deliver 300kW. Delivering 300kW for 21min would require 105kWh. Batteries will often be oversized so they can operate more efficiently, have reserve power available, have a longer lifetime and deliver enough power for the application.

There are many technical tradeoffs to make in selecting and specifying a good battery buffering solution, please contact Heliox to help refine your needs and select solutions together.

Battery Buffering Design Drivers

- **Output Power:** (e.g. 450kW)
  - The maximum power you need to charge
  - Driven by the charging needs and maximum rating of vehicle
- **Input Power:** (e.g. 150kW)
  - The average power you need to draw from the grid
- **Battery Size:** (e.g. 100kWh)
  - At least Maximum Continuous Charge Time x Charge Power
  - Many other factors to optimize
- **Space:**
  - Battery buffered chargers can be smaller than opportunity chargers

Different Types of Battery Buffered Solutions

The are two main ways of integrating a battery buffer into an electric vehicle charging site, AC coupled, and DC coupled solutions. AC Coupled solutions are usually much larger and less efficient than DC coupled solutions. To understand why, we need to look at the difference between AC-DC and DC-DC converters.

Converter Stages

Chargers and battery buffer systems are built out of two types of power conversion functions to take the AC and deliver DC to a vehicle, AC-DC converters and DC-DC converters:

- AC-DC Converters are always needed to convert the grid AC into the DC required for a battery. They are however usually physically larger for the same power, less efficient and more expensive than DC-DC converters. With AC (Alternating Current) the input voltage is always changing (alternating) there is a wide range of input voltages the converter needs to deal with. This is like selecting a bus for a route which alternates between 3 and 80 people, you need to have a larger more expensive bus, which will on average be half full.

- DC-DC converters (non-isolated in this case for the technical reader) are usually much smaller, cheaper and more efficient for the same power. They are required when going from one battery into another battery since the voltages will be different. DC-DC (Direct Current) converters usually convert between two roughly constant voltages. To continue the bus analogy, a DC-DC converter for this case is like selecting a bus for a route which has between 40 and 43 people using it – you can pick a smaller bus and it is almost always full. This lets it be smaller, cheaper and more efficient than an AC-DC converter for the same power.

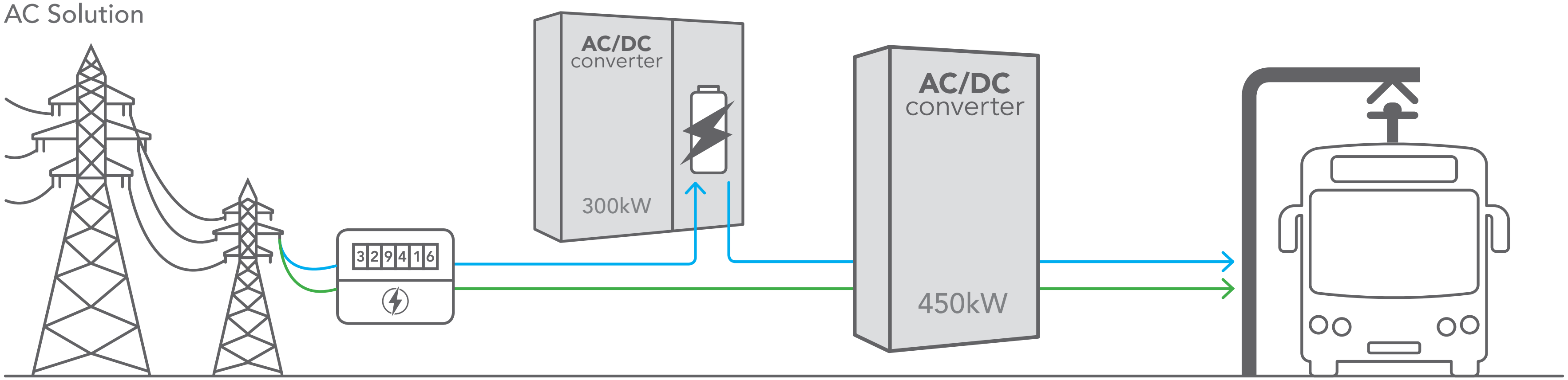
AC Coupled
Low efficiency due to 3 AC-DC conversion steps
Higher cost due to two large, and expensive AC-DC converters (450kW for the charger, and 300kW for the battery in the above case)
Increased complexity since the demand needs to be monitored and reacted to by separate systems
Larger – requires two, more powerful, bulky single purpose converters

AC Coupled

An AC coupled battery buffer consists of two large, high power AC-DC converters. The first, a battery pack with a bidirectional AC-DC converter is also a battery backup UPS (Uninterrupted Power Supply) system. The second is the AC-DC converter for the charger. The stored energy flows through the battery backup AC-DC converter to the battery, then back through the AC-DC converter to AC, then to the charger to be converted again from AC to DC. These steps add considerable inefficiency.

The AC connection between the battery and the charger means the energy can be used with any types of chargers, or anything on your power grid either as a backup or to help with peak shaving. It is however more complex to control since the battery unit needs to be coordinated with the charger or other loads.

AC Solution



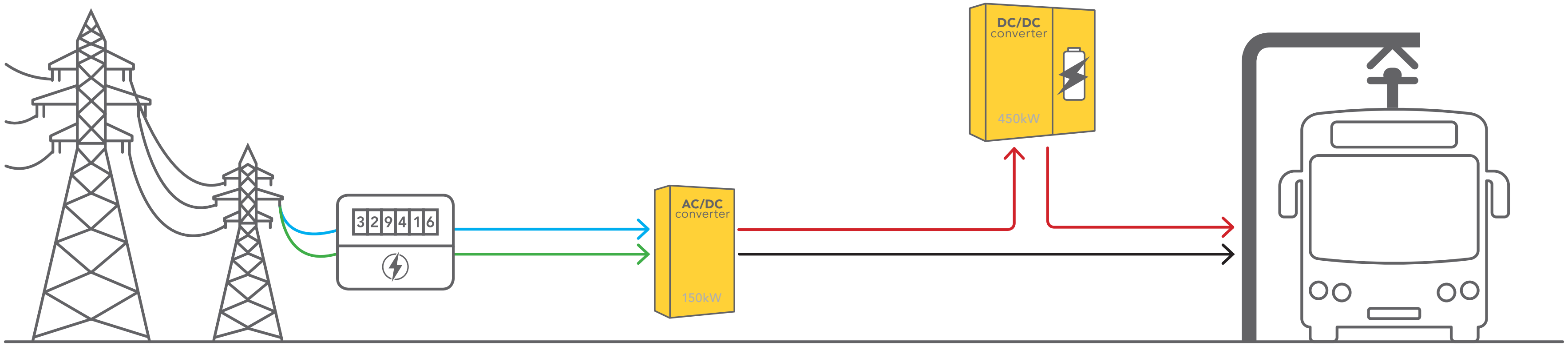
DC Coupled
High efficiency due to a single AC-DC conversion step plus a single high efficiency DC-DC conversion step
Lower cost (single 150kW AC-DC converter, plus smaller, more efficient 300kW DC-DC converter)
Automatic peak shaving. Each charger is able to regulate its own demand either automatically, or centrally controlled via OCPP etc.
Smaller, compact charger

DC Coupled

In contrast DC coupled solutions integrate the battery buffer into the charging station itself. A single AC-DC converter is used to convert the grid power to the power for the battery storage, or to the vehicle directly when not running in battery mode. When higher powers than the AC input are required a much smaller, integrated DC-DC converter is used to add power directly from the battery to the charging without the inefficiency of converting to AC and back again. This also allows the AC-DC converter to be much smaller since it is only the size needed for the average input power, instead of the size required for the full output power. The DC-DC converter makes up the difference in power but with a much smaller size and lower cost.

DC coupled solutions also automatically peak shave their consumption, and therefore no complex sitewide energy management is required, however, they can be actively management to reduce demand even further. Bidirectional DC coupled battery buffers can still act as AC coupled storage for other charging stations or loads.

DC Solution



When to use a battery buffered charger?

- **Periodic on-route opportunity charging.**
  E.g. bus timetable every >10min.

- **Depot opportunity charging with multiport outlets** and peak use periods. E.g. many buses wanting to opportunity charge around lunchtime, where the highest peak demands can be serviced by battery buffering.

- **Overnight chargers** (low power continuous) which double as occasional use opportunity chargers (high power sprint) during the day.

- **Fleet or public chargers** servicing a variety of vehicles or needs where higher power charge rates (350kW) are infrequent compared with lower power (<150kW) charging.

When not to battery buffer?

There are cases where battery buffering won't be the best solution, and you should consider a traditional grid-connected opportunity charger.

- If your **route is very frequent**, the savings from battery buffering drop. If you have a frequent route at 10 times per hour (or combination or routes sharing a charging stop), then it could require 50min of charging time per hour. The input average power will then need to be 375kW for a 450kW opportunity charger, so the grid peak power savings are lower. The battery buffer can only deliver a fast charge for a fixed period determined by the battery size. If delays cause a long period of continuous charging, the battery might run out leaving the charger only able to deliver its input power.

- If other loads already force you to have a **much higher peak grid connection**. For example, at a depot the grid connection size might be driven by the needs for overnight charging, rather than the peaks seen during the day for opportunity charging.

Battery buffering considerations

Battery buffering adds a few complexities compared to traditional charging.

- **Batteries wear out over time and cycles.** Batteries in a battery buffer opportunity charger will be cycled many times per day, though rarely fully discharged. A 100kWh battery buffer in the above 3 bus per hour case could be cycled equivalent to 17 times per day. Some battery types like LTO are well suited to this and could last 10 years under these conditions, while other battery types could wear out after 6 months. Increasing the size of the battery beyond the minimum required can help you extend the cycle life but adds cost.

- Battery buffering **won't be as efficient as direct charging from the mains** since the energy is stored in a battery and converted twice instead of once in direct charging. Depending on the charger and battery this can add a few % to your energy consumption which you should consider in your business case.

Smart Grid & Virtual Power plants

Battery Buffer systems can be an important part of smart grids and function as virtual power plants reducing consumption or putting power back onto the grid, provided they are bidirectional. As energy production moves more towards variable renewable energy sources like solar and wind it will become more important for loads on the power grid to be able to react quickly to changes in supply. Smart grids where energy users can earn money using their existing equipment to help balance the power grid load are becoming increasingly important.

- **Energy arbitrage** (also called **load shifting**) is the simplest form of 'virtual power plant'. This is where you store up energy when it is cheap, and use or sell it back when it is more expensive. This can be as simple as a timer on your electric hot water tank which only heats the water with cheaper energy at night. With a battery you could either use the energy or return it to the grid for a profit. For overnight or depot charging this is a very easy way to save money by delaying charging until the energy is cheaper.

  Storing cheap energy at night, and using it during the day can save some money, for example going from $0.230/kWh at night to $0.281/kWh during the day[1]. With a 100kWh battery you could save $5.10 per day, or $1,861 a year. This is far below a profitable payback for the battery by itself, but can be an extra financial bonus if battery buffering is needed for other reasons.

- **Demand Response** is starting to be used by utilities. Utilities often face significant costs to install the generation capacity required for the highest consumption days of the year. For example the hottest 10 days in California when the air-conditioning loads are highest. In response utilities are setting up systems and pricing incentives for consumers to reduce energy consumption in response to a demand from the utility. For example a utility sends a signal to users indicating tomorrow is a "Peak Day Pricing" day, where higher than normal tariffs, or incentives for lower consumption, will apply. Energy consumers can then adjust their consumption patterns to minimize the load.

[1] PG&E A1 tariff https://www.pge.com/en_US/small-medium-business/your-account/rates-and-rate-options/time-of-use-rates.page

Versions of this operate on windows from days down to minutes. Demand Response is evolving quickly as utilities are better able to predict and communicate use and increasing Internet of Things (IoT) controlled devices are better able to listen and respond to the demand.

- **Ancillary Services** are similar to demand response but are often in place already at very high-power levels. Transmission level utilities already pay for smart grid services like automatic Frequency Restoration reserve (aFRR). With aFRR utilities pay to be able to command increases or decreases in electrical generation or loads automatically within minutes to help them balance out the energy production (for example, as a gust of wind increases production) with demand. At the fastest, there is 'Frequency Control Reserve' where the user measures the grid frequency and is contracted to deliver power within seconds if the frequency is too low or consume power if the frequency is too high. These markets can be quite profitable and are currently driving substantial investment in installing battery packs for grid scale energy storage.

Currently the regulations often require a large minimum power level, for example in the Netherlands 1MW, and long availability times, for example 1 week, to participate in these markets. Today these services can often only be used by power generation companies and the largest industrial users. As demand for these regulation services increases, utilities are relaxing these rules and lowering the barriers allowing smaller power levels and shorter time periods. Fortunately, with aggregation many chargers and other devices can be grouped together to meet the tough utility requirements and participate collectively. Grid services aggregation is developing rapidly and dual-use devices like battery buffered chargers will be able to earn additional revenue.

- **Distributed Energy Resources** will eventually reduce the requirements for huge transmission grids. As renewable energy production like wind and solar becomes more common, energy can be produced near where it is used. Local energy storage can be an essential ingredient to bridge the time between when the energy is produced and consumed.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Distributed Energy Resources are in the early stages and will operate on a foundation of demand response type functions.

- **Vehicle-2-Grid (V2G)** capability can also extend the available capacity by using the vehicle battery in addition to a charger battery. With V2G you can delay charging, or even reverse and deliver power to the grid if the demand, and price, is high enough. The reason for opportunity charging, of getting a vehicle back to work quickly, doesn't align well with delaying or reversing charging to provide V2G services. However if the charger is also used overnight, then V2G can potentially provide another revenue stream.

Bi-directionality is an important aspect of future proofing your investment. Battery buffered charging solutions will in future allow you generate additional revenue from smart grid services.

Heliox

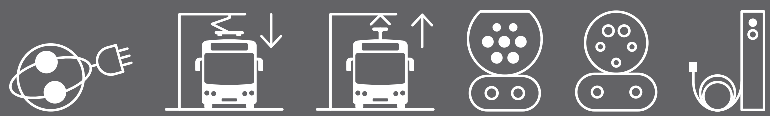
Heliox is the **global market leader** in fast charging systems within public transport, marine, mining and port equipment. The premium quality and highly efficient chargers enable operators to improve their performance while lowering environmental impact. Heliox operates on a global level with headquarters in the Netherlands and local offices in the UK, Australia, Singapore, India and the US.

Case Analysis

Heliox in house expertise and analysis tools can help evaluate different charging strategies. We can help you evaluate which of our portfolio of products will best suit your needs. For large depots we can often help you find optimizations which work seamlessly with your operations to let you deliver the same charging capacity with less infrastructure.

SprintCharge

The Heliox SprintCharge is a Battery Buffered Opportunity charger which can help you realize grid connection cost savings. Find out more at www.heliox.nl



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