Hybrid Electric Vehicles: **EE 6435 D**

Module 4

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Methods of Charging

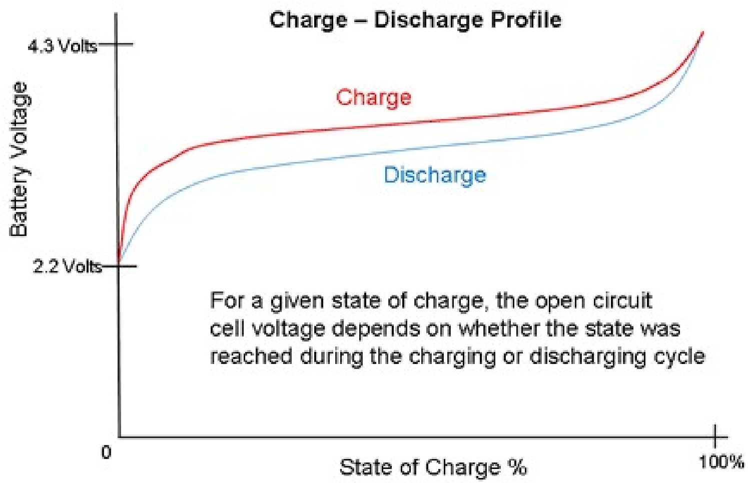
Constant Voltage A constant voltage charger is basically a DC power supply which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery. Such simple designs are often found in cheap car battery chargers. The lead-acid cells used for cars and backup power systems typically use constant voltage chargers. In addition, lithium-ion cells often use constant voltage systems, although these usually are more complex with added circuitry to protect both the batteries and the user safety.

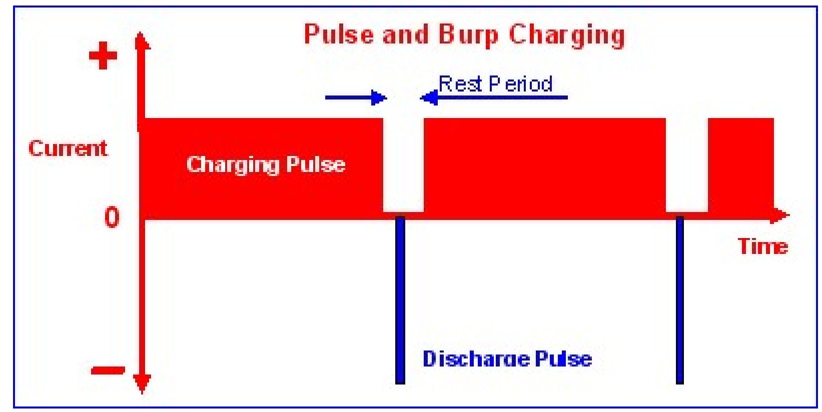
Constant Current Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge. This design is usually used for nickel-cadmium and nickel-metal hydride cells or batteries.

Taper Current This is charging from a crude unregulated constant voltage source. It is not a controlled charge as in V Taper above. The current diminishes as the cell voltage (back emf) builds up. There is a serious danger of damaging the cells through overcharging. To avoid this the charging rate and duration should be limited. Suitable for SLA batteries only.

Pulsed charge Pulsed chargers feed the charge current to the battery in pulses. The charging rate (based on the average current) can be precisely controlled by varying the width of the pulses, typically about one second. During the charging process, short rest periods of 20 to 30 milliseconds, between pulses allow the chemical actions in the battery to stabilize by equalizing the reaction throughout the bulk of the electrode before recommencing the charge. This enables the chemical reaction to keep pace with the rate of inputting the electrical energy. It is also claimed that this method can reduce unwanted chemical reactions at the electrode surface such as gas formation, crystal growth and passivation. If required, it is also possible to sample the open circuit voltage of the battery during the rest period.

Methods of Charging





The optimum current profile depends on the cell chemistry and construction

Burp charging Also called **Reflex** or **Negative Pulse Charging** Used in conjunction with pulse charging, it applies a very short discharge pulse, typically 2 to 3 times the charging current for 5 milliseconds, during the charging rest period to depolarize the cell. These pulses dislodge any gas bubbles which have built up on the electrodes during fast charging, speeding up the stabilization process and hence the overall charging process. The release and diffusion of the gas bubbles is known as "burping". Controversial claims have been made for the improvements in both the charge rate and the battery lifetime as well as for the removal of dendrites made possible by this technique. The least that can be said is that "it does not damage the battery".

IUI Charging This is a recently developed charging profile used for fast charging standard flooded lead acid batteries from particular manufacturers. It is not suitable for all lead acid batteries. Initially the battery is charged at a constant (I) rate until the cell voltage reaches a preset value - normally a voltage near to that at which gassing occurs. This first part of the charging cycle is known as the bulk charge phase. When the preset voltage has been reached, the charger switches into the constant voltage (U) phase and the current drawn by the battery will gradually drop until it reaches another preset level. This second part of the cycle completes the normal charging of the battery at a slowly diminishing rate. Finally the charger switches again into the constant current mode (I) and the voltage continues to rise up to a new higher preset limit when the charger is switched off. This last phase is used to equalize the charge on the individual cells in the battery to maximize battery life.

Methods of Charging

Trickle charge Trickle charging is designed to compensate for the self discharge of the battery. Continuous charge. Long term constant current charging for standby use. The charge rate varies according to the frequency of discharge. Not suitable for some battery chemistries, e.g. NiMH and Lithium, which are susceptible to damage from overcharging. In some applications the charger is designed to switch to trickle charging when the battery is fully charged.

Float charge. The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery's upper voltage limit. Used for emergency power back up systems. Mainly used with lead acid batteries.

Random charging All of the above applications involve controlled charge of the battery, however there are many applications where the energy to charge the battery is only available, or is delivered, in some random, uncontrolled way. This applies to automotive applications where the energy depends on the engine speed which is continuously changing. The problem is more acute in EV and HEV applications which use regenerative braking since this generates large power spikes during braking which the battery must absorb. More benign applications are in solar panel installations which can only be charged when the sun is shining. These all require special techniques to limit the charging current or voltage to levels which the battery can tolerate.

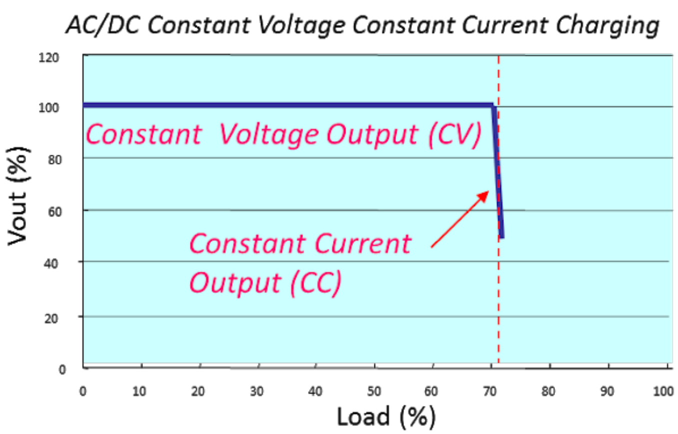
Charging Rates:

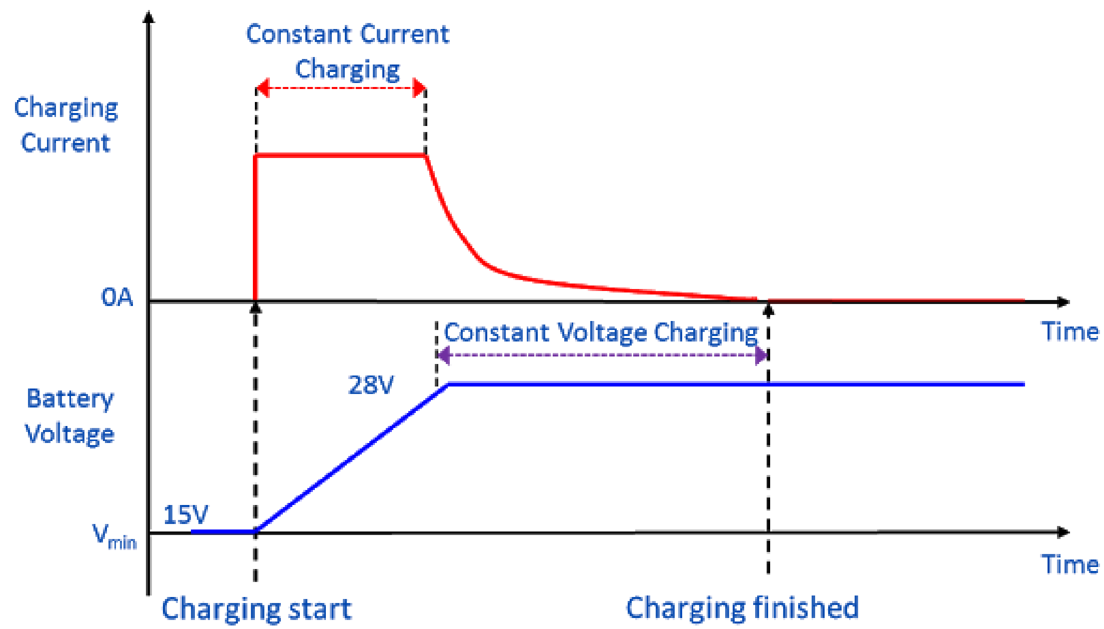
Batteries can be charged at different rates depending on the requirement. Typical rates are shown below:

Slow Charge = Overnight or 14-16 hours charging at 0.1C rate
Quick Charge = 3 to 6 Hours charging at 0.3C rate
Fast Charge = Less than 1 hour charging at 1.0C rate

Methods of Charging

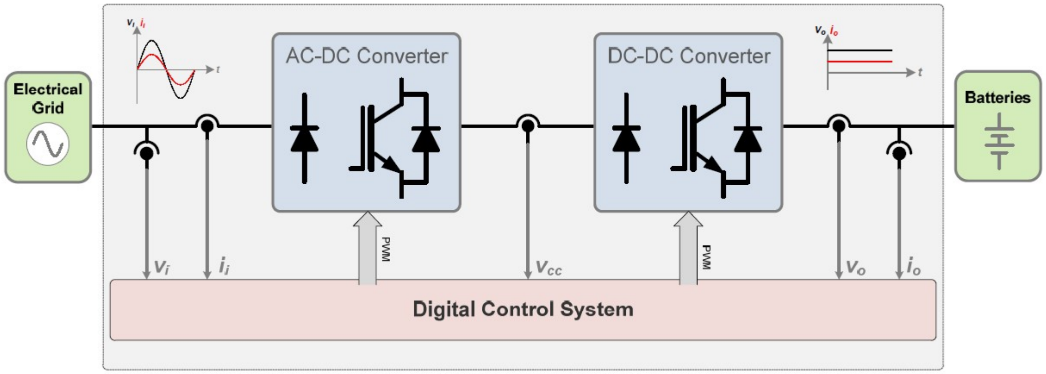
Constant voltage / constant current (CVCC) is a combination of the above two methods. The charger limits the amount of current to a pre-set level until the battery reaches a pre-set voltage level. The current then reduces as the battery becomes fully charged. This system allows fast charging without the risk of over-charging and is suitable for Li-ion and other battery types.



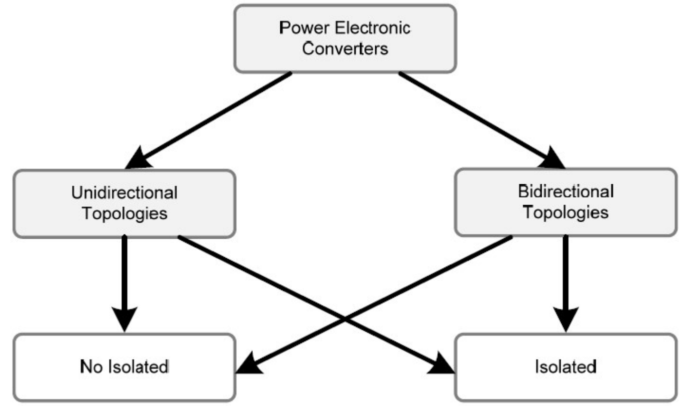


Smart charging involves the use of a micro-controller to compensate for temperature rise and adjust the charge current and charge time accordingly to the battery specifications. This extends battery life and is used with Li-ion battery types. This battery management circuit or unit can be fitted externally to the charger. A number of the power semiconductor manufacturers offer control circuits to perform this function.

EV Charging Stations



Structure of an Electric Vehicle batteries charging system



Main categories of AC-DC power converters topologies used in EVs batteries charging systems

Charger Performance:

The battery type and the application in which it is used set performance requirements which the charger must meet.

Output Voltage Purity:

The charger should deliver a clean regulated voltage output with tight limits on spikes, ripple, noise and radio frequency interference (RFI) all of which could cause problems for the battery or the circuits in which it is used. For high power applications, the charging performance may be limited by the design of the charger.

Efficiency:

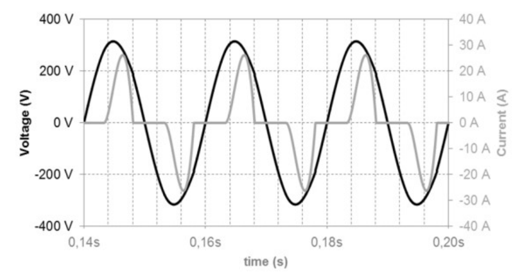
When charging high power batteries, the energy loss in the charger can add significantly to the charging times and to the operating costs of the application. Typical charger efficiencies are around 90%, hence the need for efficient designs.

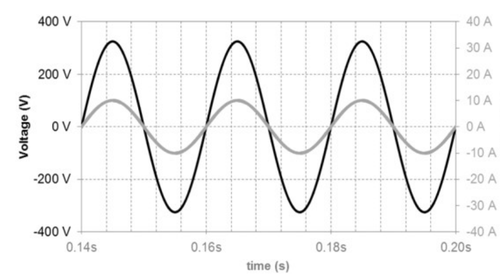
Inrush Current:

When a charger is initially switched on to an empty battery the inrush current could be considerably higher than the maximum specified charging current. The charger must therefore be dimensioned either to deliver or limit this current pulse.

Power Factor:

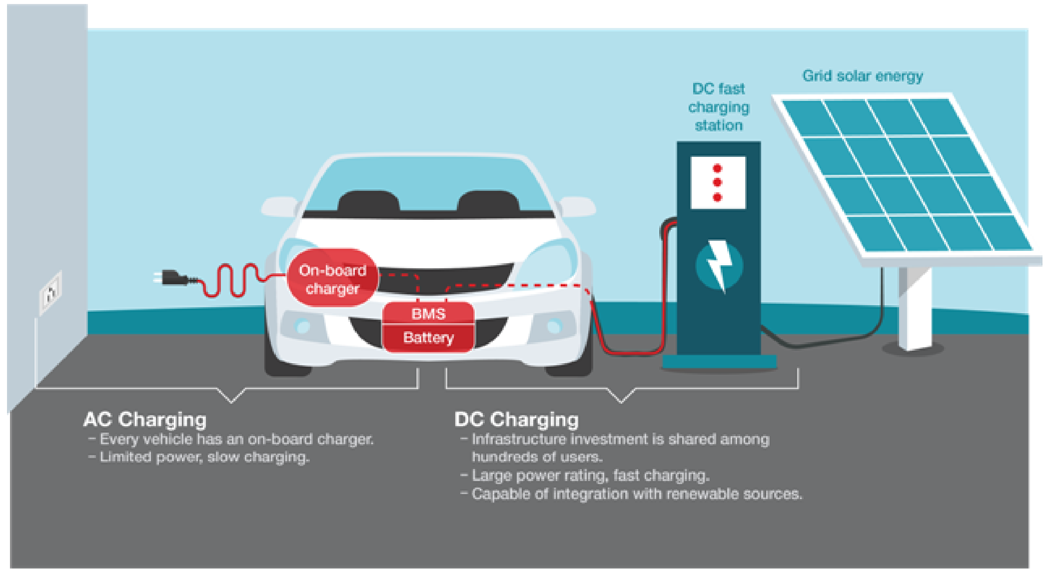
This could also be an important consideration for high power chargers.





EV Charging Stations

Differences between AC/DC charging stations and on-board chargers



Despite having separate functions for charging a vehicle, similarities in the naming conventions ("on-" and "off-" board chargers) have caused general confusion about these two systems.

However there are stark differences in not just the function of the chargers but also the voltage requirements of the chargers and how they charge the vehicle.

The power modules of an on-board and off-board charger are split based on charging power levels. The on-board charger has to condition (convert to high voltage DC) power from the off-board AC charger before supplying it to the battery management system (BMS), the off-board DC charger works without an on-board charger and directly charges the batteries in the EV.

The power modules of the on-board and off-board chargers are split based on the charging power levels. The off-board charger is generally designed to transfer higher kilowatts of power and requires a more sophisticated BMS on the PHEV. It increases the overall vehicle's efficiency as the charger is not present in the vehicle. On the other hand, an on-board charger is generally designed for lower kilowatts of power transfer and adds significant weight to a EV.

Electric Vehicle Supply Equipment (EVSE)

The equipment's that constitute an Electric Vehicle Charging Station are collectively called as **Electric Vehicle Supply Equipment (EVSE).** The term is more popular, and it refers nothing but to the charging stations. Some people also refer it as ECS which stands for Electric charging station.

An EVSE is designed and engineered to charge a battery pack by using the grid for Power Delivery; these battery packs might be present in an Electric Vehicle (EV) or in a Plug-in Electric Vehicle (PEV).

On-Board Chargers and Charging Stations

Most EVs today come with an On-Board charger (OBC) and the manufacturer also provides a Charger along with the vehicle. These chargers along with the on-board charger can be used by the customer to charge his EV home. But these chargers are very basic and do not come with any advanced features and hence would normally take around 8 hours to charge a typical EV.

Types of EV Charging Stations (EVSE)

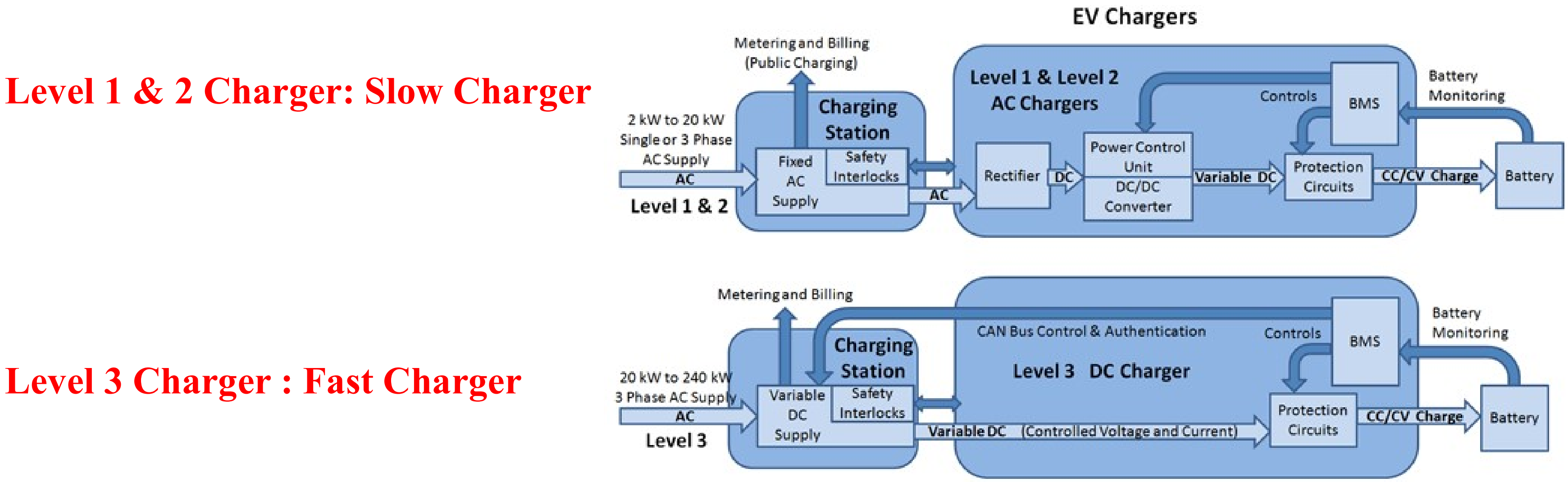
Charging Stations can be broadly classified into two types, AC charging Station and DC charging Station.

An **AC charging Station** as the name implies provides AC power form the grid to the EV which is then converted to DC using the On-board charger to charge the vehicle. These chargers are also called the **Level 1 and Level 2 Chargers** which is used in residential and commercial places.

The advantage of an AC charging station is that the on-board charger will regulate the voltage and current as required for the EV hence it is not mandatory for the charging station to communicate to the EV.

The disadvantage is its low output power which increase the charging time. A typical AC charging system is show in the below picture. As we can see the AC from grid is supplied directly to OBC through EVSE, the OBC then converts it to DC and chargers the battery through the BMS. The Pilot wire is used to sense the type of charger connected to the EV and set the required input current for the OBC.

Electric Vehicle Supply Equipment (EVSE)



A **DC charging Station** gets AC power form the grid and converts it to DC voltage and uses it charge the Battery pack directly by by-passing the On-board Charger (OBS). These chargers normally output high voltage of upto 600V and current upto 400A which enables the EV to be charged in less than 30 minutes as compared with 8-16 hours on AC charger.

These are also called **Level 3 chargers** and commonly known as DC Fast Chargers (DCFC) or Super chargers.

The advantage of this type of charger is its fast charging time while the disadvantage is its complex engineering where it needs to communicate with EV to charge it efficiently and safely.

A typical DC charging system is shown below, as you can see the EVSE provides DC directly to Battery pack bypassing the OBS. The EVSE is arranged in stacks to provide high current a single stack will not be able to provide high current due to power switch limitations.

Electric Vehicle Supply Equipment (EVSE)

Charging Station Type	**Charger Level**	**AC Supply Voltage and Current**	**Charger Power**	**Time to charge a 24kWH battery Pack**
AC charging Station	Level 1 - Residential	Single Phase – 120/230V and ~12 to 16A	~1.44 kW to ~1.92kW	~ 17 Hours
AC charging Station	Level 2 - Commercial	Split Phase – 208/240V and ~15 to 80A	~3.1 kW to ~19.2 kW	~ 8 Hours
DC charging Station	Level 3 – Supercharger	Single Phase – 300/600V and ~400A	~120 kW to ~240 kW	~ 30 minutes

Normally the **Level 1 chargers are meant for residential use**, these are the chargers that are provided by the manufacturers along with the EV which can be used to charge the EV through standard house power outlets. So **they work on Single phase AC supply** and can output anywhere between 12A to 16A and takes about 17 hours to charge an EV of 24kWH. A **Level 1 charger has not much role in charging stations.**

The **Level 2 charger** is provided as an update for level 1 charger **it can either be installed in house**, on special request provided the house has split phase power supply **or can be used in public/commercial charging stations** as well. These chargers can provide upto 80A output current due to its high input voltage and can charge an EV in 8 hours. The **Level 3 charger or Super chargers** are meant for public charging stations alone. They require poly phase AC input from the grid and consume more than 240 kW which almost 10 times more than a typical Air conditioning unit in our home. So these chargers require special permission from the grid to operate.

The **Level 2 and Level 3 chargers are considered to be more efficient than the Level 1 charger** since the AC/DC and DC/DC conversion takes place in the EVSE itself. Because of the huge size and complexity of a Level 2 and Level 3 chargers they cannot be built inside a EV as it would increase the weight and reduce the efficiency of the EV.

Electric Vehicle Supply Equipment (EVSE)

EVSE AC Charging Station - Level 1 and Level 2 Chargers

The **Level 1 chargers have a maximum output current of 16A** because of the limitations of household power sockets, while the **Level 2 chargers can provide upto 80A** when operated in Three Phase supply.

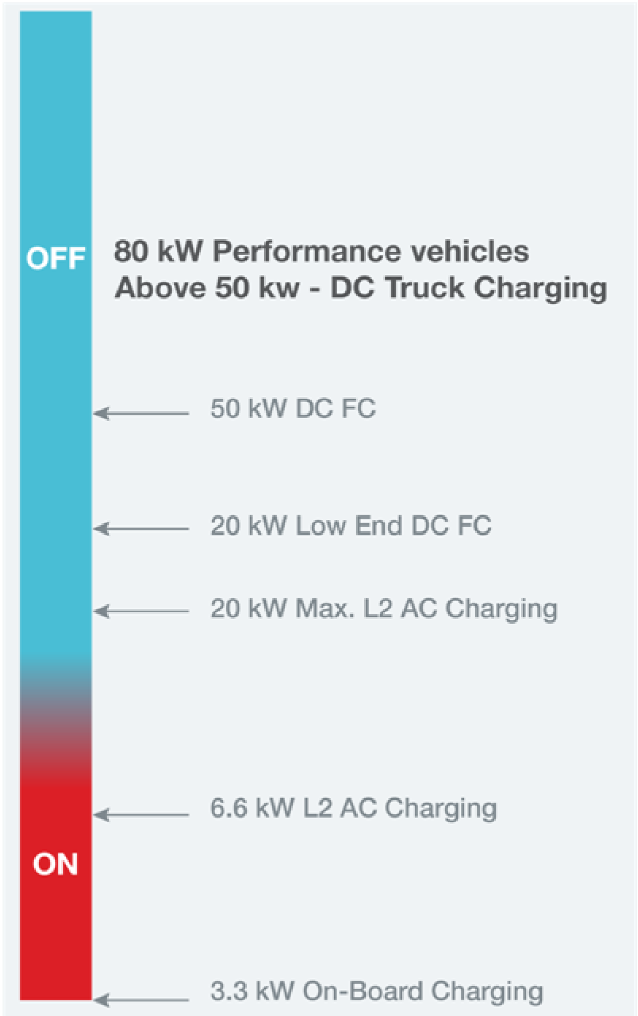
This relay will be closed to begin the charging process and opened when charging is completed. The Pilot Signal communication is used to detect battery status and the host processing system decides how much power should be supplied to the on-board charger.

EVSE DC Charging Station - Level 3 Chargers

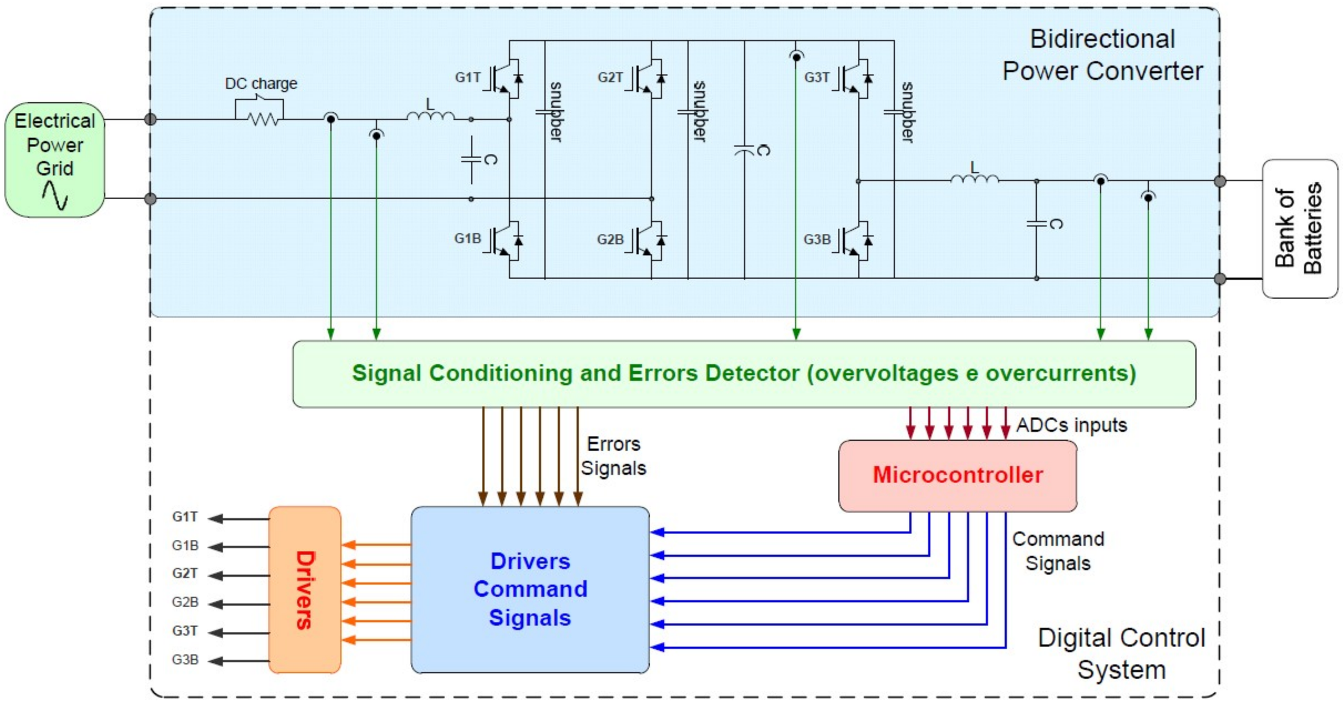
The system here is over simplified by removing the systems that we discussed earlier in the AC charging system. The **Level 3 charger always works on a three phase AC supply**, so the AC/DC converter has to take in the 3 Phase supply and convert it to 40V or higher DC.

This DC voltage will then be stepped up to higher level (350 -700 V) as required by the battery pack.

The Output Voltage and Current will be decided by the **BMS of the EV** which will then be communicated to the EVSE through CAN/PLC communication.



EV Charging Stations : Circuit Configuration



Schematic of the developed Electric Vehicle batteries charging system.

It was developed a laboratory prototype of a 3 kW batteries charging system that works with sinusoidal current consumption and unitary power factor, and that allows the charging of the batteries with different algorithms: constant-voltage, constant-current, and constant current followed by constant-voltage; in accordance with the State-of-Charge (SoC) level of the batteries and with their technology, namely, lithium, nickel, and lead-acid.

EV Charging Stations : Circuit Configuration

Setting up an Electric Vehicle Charging Station in India

With EVs getting quickly popular in India, we can already notice many EVSE set-ups popping up in major cities of India. With regulations still being standardized for India the following are the common problems with setting up an EVSE in India.

1. Low Charge Rate for Indian EVs: The EVs in India are still not ready for Level 3 or Super chargers as their battery packs do not support fast charging. How fast a battery could charge depends on its C rating, Indian EVs still have very low C rating that even a Level 2 charger is not required for most EVs. This will create less demand for public EVSE.

2. Electricity Re-Sale Problem: According to norms you are not allowed for direct Re-Sale of electricity. Only the DISCOM is allowed to sell electricity. However with pressure from ISGF the Charging stations might be considered as an expectation for this in the future.

3. Weak Distribution Transformers: Most of the Distribution Transformers (DT) in India is already overloaded. An EVSE will consume high power from the grid making it a heavy problem. Hence the complete DT in that area has to be replaced with higher rating ones. This will be a major problem as new EVSE starts popping up in the city.

EV Charging Stations : Circuit Configuration

- ✓ In recent years the problems of "range anxiety" associated with electric vehicles (EVs) have been alleviated by the introduction hybrids (HEVs) and plug in hybrids (PHEVs) and the development of higher energy density batteries capable of storing more energy in the same space. With the increasing popularity of electric vehicles, "range anxiety" is now being replaced by "charging anxiety".
- ✓ It takes about three minutes fill up a petrol or diesel engine car at a filling station with enough fuel to travel about 300 miles. To travel 300 miles in a small EV passenger car would need three full charges of a typical 25 kWh battery used to power.
- ✓ Unfortunately to put the 25 kWh of energy needed to travel each 100 miles into the battery in the same time (1 minute) that the equivalent amount of diesel fuel is pumped into the tank would require a power supply capable of delivering a power of 1.5 Mega Watts.
- ✓ To put this into perspective, 25 kWh is the amount of energy an average household consumes in a whole day. Providing electrical distribution facilities to allow users to consume this amount of energy from the electricity grid in one minute is not practical and even if it was, no EV battery could accept energy at this rate. On the other hand neither is it practical to take 24 hours to charge the battery in a passenger electric vehicle.

EV Charging Opportunities

One of the main reasons given for range anxiety was the possibility that there would be no, or few, charging facilities remote from the home base adding unacceptable risk to long journeys. While this is still the case, there's a much greater problem closer to home.

Charging at Home:

Though some EV enthusiasts may live in leafy suburbs in houses with garages and driveways where they can connect their cars to the electricity supply, a very large percentage of the population, live in streets without gardens and have to park their cars in the street.

They can not run an extension leads across the pavement to their cars to charge the battery overnight. Similarly the parking facilities for apartment dwellers may be in open parking lots with no access to electrical power. Even if the apartments have indoor parking spaces, these not usually equipped with electrical power outlets.

The charging stations would also need to include authentication and billing systems and the communications to manage them. It may be possible to offer charging facilities in company parking lots but it is not really practical in a residential area.

EV Resale Values

For those fortunate live in houses with private parking, able to charge their vehicles at home, another issue arises. When they come to change or upgrade their EVs, their old EVs will be resold through the used car market, usually to buyers more likely to be living in less affluent communities without the luxury of private parking. The lack of parking facilities in their target market will no doubt have a negative effect on resale values.

EV Charging Opportunities

Charging Away from Home

Parking:

It may seem strange that parking is relevant to charging opportunities. It is not because of the access to the charging station, but because of the cost of the parking which can far outweigh the cost of the electricity. As noted above, the 25 kWh of energy takes about 6 hours to charge. But typical city center parking costs for 6 hours parking could be anywhere between Rs. 200 and Rs. 300 depending on the city.

Service Times:

Fast charging stations were designed to be installed in motorway service stations to enable EV owners to undertake long journeys exceeding the normal operating range of their vehicles. The fast charging systems employed are very expensive to install.

This should not be a major problem when the population of EVs is also very small, nevertheless if several EVs turn up at the same time at the charging station, with charging times of up to 30 minutes or more, the last in the queue will have to wait a long time before the vehicle can be charged. This could make club outings of EV owners groups very difficult. If the popularity of EVs eventually takes off the result could be impossible congestion.

EV Charging Opportunities

Planning and Regulatory Issues:

Providing public charging facilities could be an attractive business proposition in the some circumstances, fulfilling a demonstrated need. Such services are still unusual and obtaining planning approval for such ventures is fraught with difficulties.

Even if these difficulties are overcome, there's still the electricity utility to deal with. Providing power to several Level 1 and Level 2 charging stations or a single Level 3 charging station can overload their existing distribution network and a business case must be made for installing new capacity.

Equipment Standards:

Standards are another factor causing charging anxiety. There are almost as many connector standards suitable for Level 1 chargers as there are nations. The situation with Level 2 and Level 3 chargers is much better with fewer variants but compatibility between standards is still a problem.

Mennekes AC Coupler

IEC 62196 Type 1 AC Socket

IEC-62196-2 Type3 SCAME 3 Phase AC Coupler

SCAME AC Plug with Safety Shutters

CHAdeMO DC Plug

China GB Standard DC and AC EV Charging Plugs

SAE J1772 AC Coupler

J1722 AC and DC "Combo" Coupler

There is still no single worldwide standard for electrical and mechanical interfaces between chargers and charging stations and for authentication and billing systems.

Battery Swapping Technology

Benefits:

- ✓ Controlled charging Strategy in terms of scheduling battery charging time
- ✓ Postpone the charging of batteries to the night time or off-peak hours.
- ✓ From the power system perspective, the BSS can be treated by 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.

Research Challenges:

- ✓ Variety of Charging mode (Slow/Medium/Ultra-Fast)
- ✓ Isolated Charger with smooth power exchange
- ✓ Battery management System for proper utilization of Solar PV and Grid
- ✓ UPF enabled and charge traffic update APP

Battery Swapping Technology

Swapping battery makes business sense

- ✓ An Energy Operator (EO) purchases battery and leases charged batteries taking into account depreciation, interest costs and charging and swapping costs
  - ✓ Most sensitive element impacting charge per km is vehicle efficiency (km/kWh).
  - ✓ Battery costs per kWh, battery life cycles, air-conditioning costs and electricity costs matter
- ✓ As price of battery decreases, swappable battery could cost lesser
  - ✓ margins for energy operator would improve
- ✓ As swappable Batteries have small life of about 4 years, early-investment not much affected
- ✓ Swapping will work, only when a user finds close-by station to swap batteries
  - ✓ In the beginning, existing petrol stations could be used side-by side selling petrol
  - ✓ Next, expand to more stations as demand grows
- ✓ For an electric bus, swapping facility could be installed and operated at the bus-depot
  - ✓ To begin with few routes of one depot can be fully electrified and be given swapping infrastructure
  - ✓ Gradually all routes and all buses of the depot can be electrified

Battery management System (BMS)

Cell Protection Protecting the battery from out of tolerance operating conditions is fundamental to all BMS applications. In practice the BMS must provide full cell protection to cover almost any eventuality. Operating a battery outside of its specified design limits will inevitably lead to failure of the battery. Apart from the inconvenience, the cost of replacing the battery can be prohibitive. This is particularly true for high voltage and high power automotive batteries which must operate in hostile environments and which at the same time are subject to abuse by the user.

Charge control This is an essential feature of BMS. More batteries are damaged by inappropriate charging than by any other cause.

Demand Management While not directly related to the operation of the battery itself, demand management refers to the application in which the battery is used. Its objective is to minimise the current drain on the battery by designing power saving techniques into the applications circuitry and thus prolong the time between battery charges.

SOC Determination Many applications require a knowledge of the State of Charge (SOC) of the battery or of the individual cells in the battery chain. This may simply be for providing the user with an indication of the capacity left in the battery, or it could be needed in a control circuit to ensure optimum control of the charging process.

SOH Determination The State of Health (SOH) is a measure of a battery's capability to deliver its specified output. This is vital for assessing the readiness of emergency power equipment and is an indicator of whether maintenance actions are needed.

Battery management System (BMS)

Cell Balancing In multi-cell battery chains small differences between cells due to production tolerances or operating conditions tend to be magnified with each charge / discharge cycle. Weaker cells become overstressed during charging causing them to become even weaker, until they eventually fail causing premature failure of the battery. Cell balancing is a way of compensating for weaker cells by equalizing the charge on all the cells in the chain and thus extending battery life.

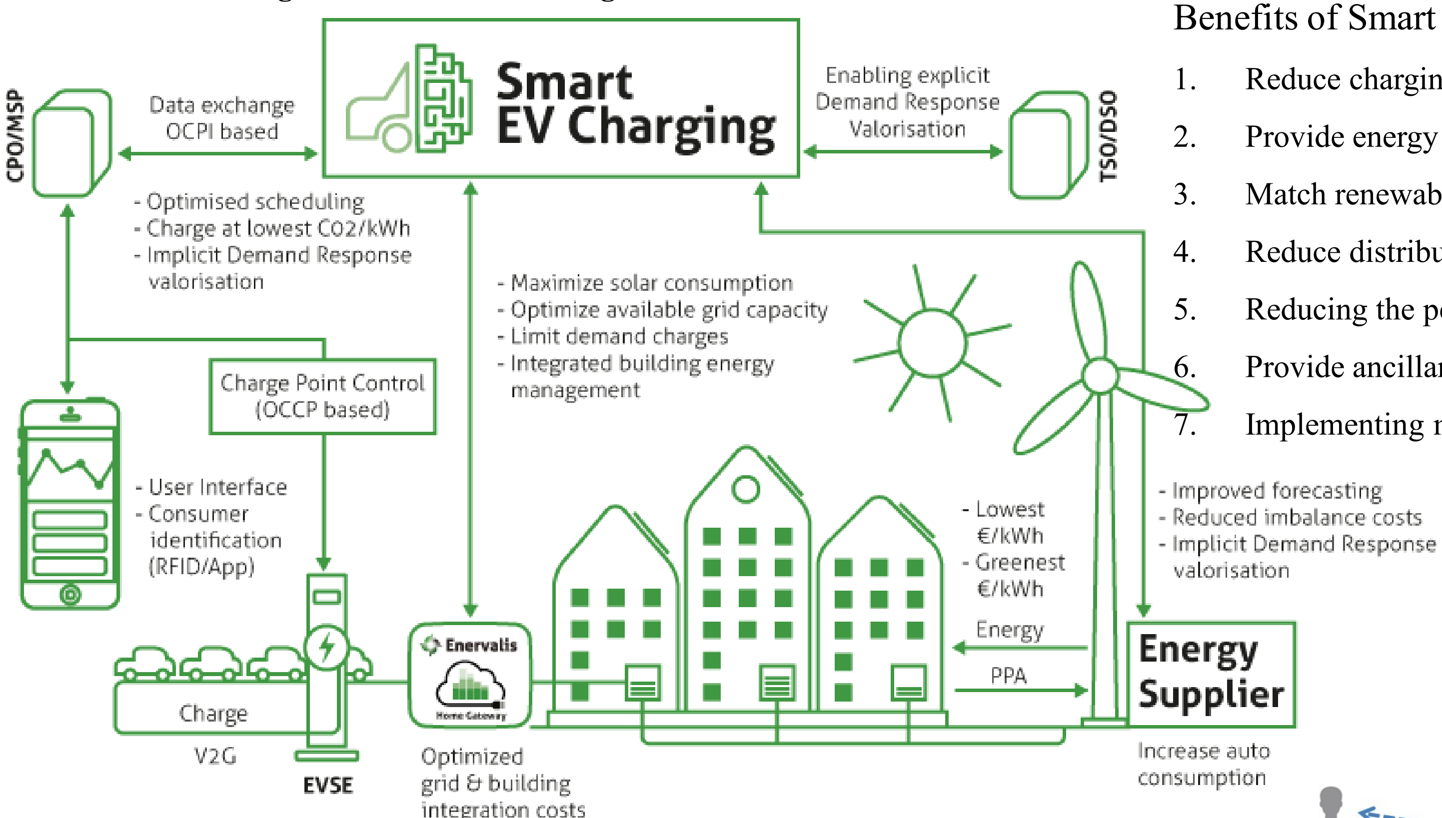
History - (Log Book Function) Monitoring and storing the battery's history is another possible function of the BMS. This is needed in order to estimate the State of Health of the battery, but also to determine whether it has been subject to abuse. Parameters such as number of cycles, maximum and minimum voltages and temperatures and maximum charging and discharging currents can be recorded for subsequent evaluation. This can be an important tool in assessing warranty claims.

Authentication and Identification The BMS also allows the possibility to record information about the cell such as the manufacturer's type designation and the cell chemistry which can facilitate automatic testing and the batch or serial number and the date of manufacture which enables traceability in case of cell failures.

Communications Most BMS systems incorporate some form of communications between the battery and the charger or test equipment. Some have links to other systems interfacing with the battery for monitoring its condition or its history. Communications interfaces are also needed to allow the user access to the battery for modifying the BMS control parameters or for diagnostics and test.

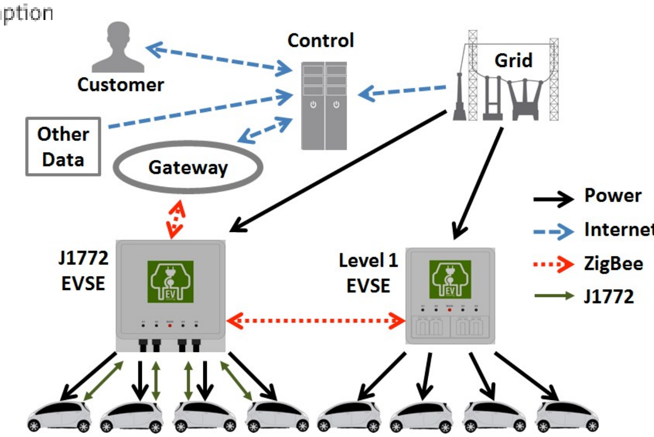
Smart EV Charger

Detailed Block Diagram of Smart EV charger



Benefits of Smart EV Charger

1. Reduce charging cost by e.g. dynamic grid prices
2. Provide energy support to grid (V2G)
3. Match renewable generation
4. Reduce distribution system losses
5. Reducing the peak demand on the grid
6. Provide ancillary services
7. Implementing multiplexing of EV chargers

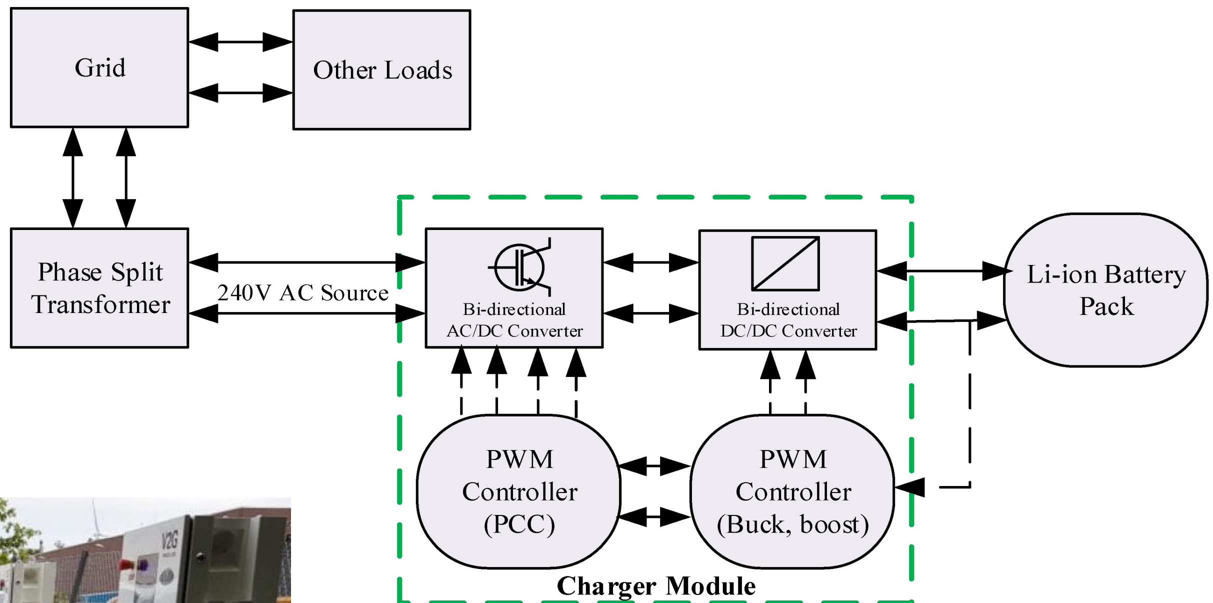


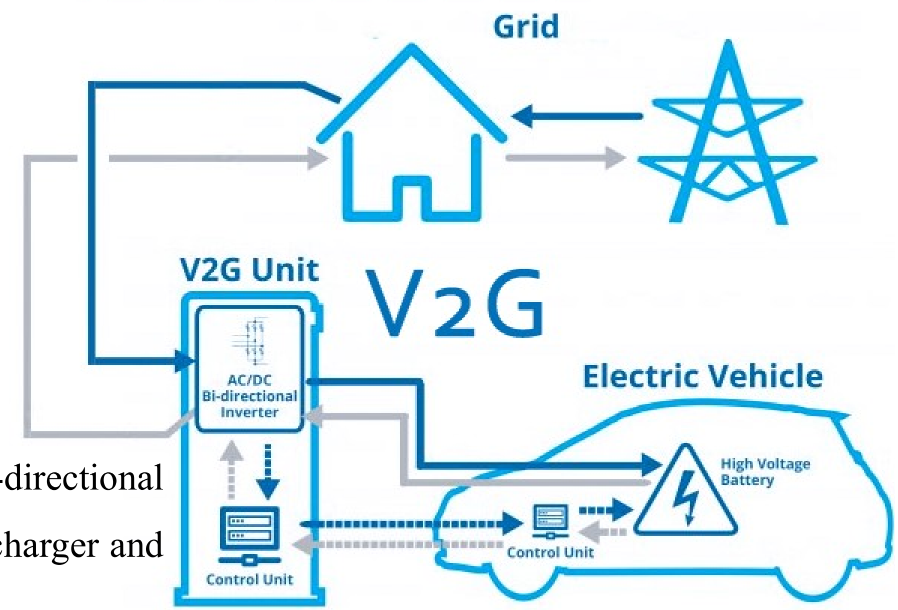
Network Architecture

Vehicle-to-Grid (V2G)

The technology to enable Vehicle-to-Grid (V2G) also called Vehicle-to-Infrastructure (V2I) and Vehicle-to-Home (V2H) is being tested and used with great success.

It promises to help boost green energy options and disrupt the automotive and electric industries.





To have V2G, you need three things, a V2G-enabled vehicle, a bi-directional charger and software to enable inter-operability between vehicle, charger and grid or building.

Challenges in Vehicle-to-Grid (V2G)

Battery wear:

- ✓ Providing V2G services may shorten the battery life owing to increased cycling and DoD. Assumptions about battery wear can have a large impact on cost estimates.

Battery replacement:

- ✓ Batteries currently cost less than Rs. 10,000/kWh. Costs for battery replacement would, in most cases, be borne by the vehicle owner.

Power electronics for V2G capability:

- ✓ Conversion between AC grid and DC vehicle current can be accomplished with power electronics incorporated into the vehicle or EVSE. V2G capability is not yet available from vehicle manufacturers. Hardware costs for bi-directional capability may be a barrier to EVSE performing grid/building services.

Network of nonresidential EVSE:

- ✓ Most vehicles are parked most of the time and could be available for V2G services for many hours per day if EVSE were available at workplaces and other locations where vehicles are parked during the day. Many studies assume full build out of EVSE infrastructure, which allows for many plugged-in hours per day.

Residential EVSE upgrades (e.g., electrical upgrades):

- ✓ Revenue for providing V2G services is highly dependent on the power (kW) that can be provided by the vehicle. Typical residential circuits limit power to about 10 kW. Upgrading residential circuits could be cost effective for providing V2G services.

Communications hardware and software:

- ✓ Communications hardware and software are needed to network vehicles and control vehicle charging and discharging. Most studies reviewed for this report do not address costs for this service.

Aggregator:

- ✓ The aggregator manages the networking and control of vehicles, bids into electricity services markets, manages contracts with vehicle owners, and may provide other products and services. The aggregator may require 40%–50% of V2G revenue to cover expenses and profit.

Challenges in Vehicle-to-Grid (V2G)

Pool of aggregated vehicles:

- ✓ Owners' driving patterns, requirements for state of charge and availability, and electricity market rules determine how many vehicles must be aggregated to provide V2G services.

Vehicle plugged-in hours:

- ✓ The number of plugged-in hours per day is a primary determinant of V2G revenue and profits. Non-residential EVSE must be available to fully realize the potential for vehicles to provide V2G services.

Power (kW) available:

- ✓ The power level that can be instantaneously available from vehicles is a primary determinant of revenue, especially for regulation services. Upgrading residential circuits to allow for higher power levels could be cost effective for vehicle owners providing V2G services.

Energy (kWh) available:

- ✓ Light-duty electric vehicle batteries have a small energy capacity in relation to the energy requirements of even micro-grids. Many vehicles would need to be aggregated together to provide bulk energy storage. The economics of price arbitrage between low and high demand periods could be challenging without large feed-in tariffs or other incentives.