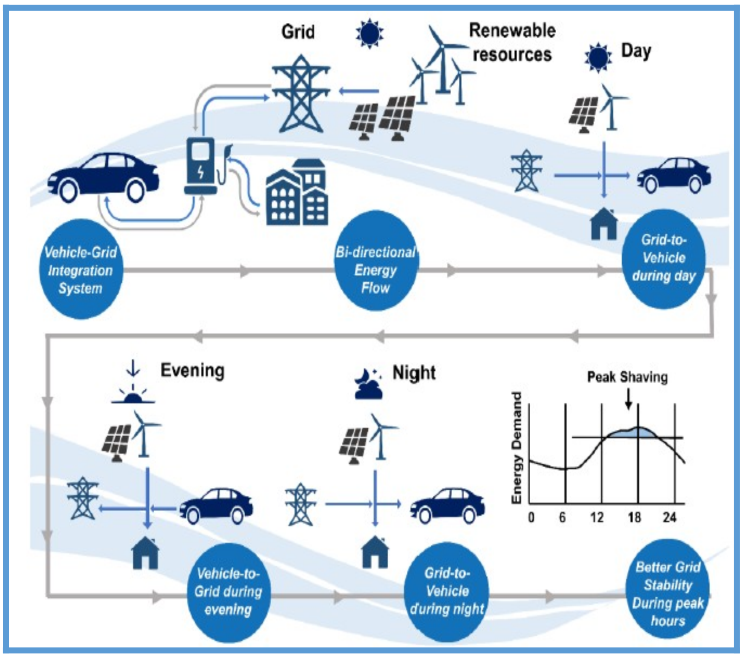

ELECTRIC VEHICLES UTILIZATION FOR VEHICLE-TO-GRID (V2G) SERVICES

Executive Summary

MoP vide O.M. dated 28.03.2023 (Annexure I) requested CEA to frame guidelines for reverse charging of grid from batteries of electric vehicles (EVs). Accordingly, a committee was constituted under the Chairmanship of Member (GO&D), CEA vide letter dated 11.04.2023 (Annexure II). The committee in its 1st meeting held on 10.05.2023 (MOM attached at Annexure III) requested to analyze various aspects of reverse charging from EVs and present it to the committee. Accordingly, a meeting of the sub-committee was held on 17.07.2023 (MOM attached at Annexure IV) with participants from IIT Bombay, IIT Delhi, IIT Roorkee, BSES Rajdhani Power Limited (BRPL), EVSE and EVs OEMs to prepare this report on EVs utilization for vehicle-to-grid (V2G) services.

This report provides a brief overview of the services that EVs can provide to the power system through smart charging, key challenges, and important factors to enable deployment, implementation requirements and way forward for the smooth integration of EVs in the grid. This report looks into bidirectional V2G technologies and on their role in integrating higher renewable energy, while providing services to the grid. Therefore, the major thrust of this report will be on planning and operation of the distribution grid with integration of EV charging infrastructure i.e. smart charging; grid support services from electric vehicles to facilitate large-scale renewable energy integration; technologies and standards for EV charging infrastructure's integration with distribution grid; policies and regulations for EV charging infrastructure and integration with distribution grid; identifying the key challenges and recommendations for efficient, effective and sustainable integration of EV charging infrastructure in India.

The cost reductions in renewable power generation make electricity an attractive low-cost fuel for the transport sector. A significant scaling up in electric vehicle (EV) deployment represents an opportunity for the power sector as well. Since, cars including EVs, typically spend about 80-90% of their lifetime parked. These idle periods, combined with battery storage capacity, could make EVs an attractive flexibility solution for the power system. Therefore, EV fleets can create vast electricity storage capacity. They can act as flexible loads and as decentralized storage resources, capable of providing additional flexibility to support power system operations.

The continued development of EV charging infrastructure and its integration will depend on the policy and regulatory framework, which must also consider the repercussions of the added EV load in the network, such as increased peak demand and congestion in the distribution grid etc. Network congestion, over voltage & under voltage issues, requirement of reactive power compensation, increase in peak load, phase imbalance issues are just a few of the many different challenges that may be witnessed by distribution utilities with high EV loads. Further, installation of the high-power chargers may warrant upgradation of the distribution infrastructure.

In this respect, implementation of smart charging is a key enabler to ensure EV uptake is not constrained by network. Smart charging would enable the distribution utility to control the EV load, thereby helping them shift the charging load to off-peak periods, which could help in deferring grid upgradation requirements. Also, with smart charging, EVs could adapt their charging patterns to flatten peak demand, fill load valleys and support real-time balancing of the grid by adjusting their charging levels. Along with leveling of the load, smart charging would help in increasing the utilization of renewable energy for EV charging.

In such scenario, key factors like standardization, interoperability, bidirectional charging system, synergies between mobility and the grid, robust bidirectional communication system, customer incentives, tariff design, optimizing of grid infrastructure requirements, integrated planning of power and transport sector, enable revenue stacking for EVs in different markets, addressing issues of battery degradation, EV load management, strategies pertaining to battery swapping, use of second life batteries, advance metering infrastructure, optimally locating the charging station from both a mobility and a power system perspective etc. may play a major role in the utilization of EVs for V2G services.

1. Introduction

MoP vide O.M. dated 20.03.2023 requested CEA to frame guidelines for reverse charging of grid from batteries of electric vehicles (EVs). Accordingly, a committee was constituted under the Chairmanship of Member (GO&D), CEA vide letter dated 11.04.2023. The committee in its 1st meeting held on 10.05.2023 requested to analyze various aspects of reverse charging from EVs and present it to the committee. Accordingly, a meeting of the sub-committee was held on 17.07.2023 with participants from IIT Bombay, IIT Delhi, IIT Roorkee, BSES Rajdhani Power Limited (BRPL), EVSE and EVs OEMs to deliberate on the issue of utilization of EVs for vehicle-to-grid (V2G) services.

The cost reductions in renewable power generation make electricity an attractive low-cost fuel for the transport sector. The International Energy Agency (IEA) has predicted that the demand for EVs charging in India to be around 83 TWh till 2030. Further, to align with our national goal of reaching net zero emission by 2070, a significant scaling up in EV deployment also represents an opportunity for the power system, with the potential to provide much needed flexibility in a system with a high share of renewables. EV fleets can create vast electricity storage capacity. They can act as flexible loads and as decentralized storage resources, capable of providing additional flexibility to support power system operations. EVs represent a paradigm shift for both the transport and power sectors, with the potential to aid the decarbornization of both sectors by coupling them. To accomplish true decarbornization of transport via electrification, the electricity used to charge the EV battery packs should be produced from renewable sources.

The smart charging means adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. With smart charging, there is certain level of control over the charging process, wherein EVs could adapt their charging patterns to flatten peak demand, fill load valleys and support real-time balancing of the grid by adjusting their charging/ discharging levels. This approach would reduce the need for investment in flexible, carbon-intensive, fossil fuel power plants to balance renewables. Further, the smart charging minimizes the load impact from electric vehicles and unlocks the flexibility to use more solar and wind power.

The smart charging, therefore, is a way of optimizing the charging process according to distribution grid constraints, utilization of distributed renewable energy sources and customers preferences. This would reduce reverse power flows and transformer overloading, enhancing the capability of grid. It also helps to mitigate voltage fluctuations in the grids having high penetration of variable renewable energy (VRE) sources. The simplest form of incentive could be – time-of-use pricing – which could encourage the EV owners to defer their charging from peak to off-peak periods. Further, the advanced smart charging approaches, such as direct control mechanisms may be necessary as a long-term solution at higher EV penetration levels and for delivery of close-to-real-time balancing and ancillary services.

The main form of smart charging include bidirectional vehicle-to-grid (V2G). V2G for electric vehicles holds the key to unleash synergies between clean transport and low-carbon economy. Batteries in cars, in fact, could be instrumental to integrate high shares of renewables into the grid. Optimally, EVs powered by renewables can spawn widespread benefits for the grid without adversely impacting the transport functionality.

2. V2G System and Infrastructure

➢ System Architecture

The system architecture associated with V2G can be classified into centralized and decentralized architectures. In a centralized architecture, the aggregator is the primary component for handling all the charging and discharging processes of the EVs. In addition, the aggregator can also perform optimization for smart charging of the EVs hence, it may have access to the system data whenever necessary. These features serve to organize the distribution system, increase the system capacity, and provide ancillary services. However, this also means that the system has a huge quantum of data to process and optimize, such as the preferred level of battery state of charge (SOC) level, available battery size, charging/ discharging time, and many more to arrive at the most optimum solution. The frequency control needs to be closely monitored with the centralized control architecture, when different vehicles are at different states of charge coupled with the uncertainty of availability of EVs at the charging stations.

On the other hand, in the local/decentralized control architecture, the local systems, such as office, factory, and apartment, etc. autonomously pursue their own way to optimize the charging cost and other parameters associated with V2G. The local systems are equipped with a server that has real-time communication with the EVs that belong to the local systems (such as employees, residents, etc.). However, this would tilt the scale in favor of probabilistic individual-made decisions. This unpredictability factor can also snowball into increasing or decreasing the electricity cost (in case of variable tariff) when a large fleet of individual vehicles chooses to vary their charging rate. This problem is expected to be less of a concern if the sample space of vehicles participating in the decentralized/local control architecture is high enough.

Control Type	**Advantages**	**Disadvantages**
Centralized control	➢ Larger scale, number of EV, and coverage ➢ Various possible ancillary services ➢ Possible different connections to transmission, distribution, and RE ➢ Smart manipulation of network capacity ➢ Possible real-time implementation ➢ Flexible and wider geographical accessibility ➢ Possible wider and larger-scale electricity market and higher possible revenue	➢ Extensive and expensive central control system, as well as the backup and storage sources ➢ Complex and expensive communication architecture and infrastructure ➢ Big data to process ➢ Demand for higher connection security (risk for privacy defilements) ➢ Possible full control of EV (the anxiety of the user that EV charging process can be interrupted at any time)
Decentralized control	➢ Smaller and simple communication infrastructure ➢ Higher control flexibility/ autonomy (charging control in the hand of the local system,	➢ Limited types of ancillary services, electricity market, and connections ➢ Smaller revenue due to limited services

	resulting in faster and convenient service) ➢ High data security as the data are stored locally ➢ Higher consumer trust and acceptance (especially during initial adoption) ➢ Scalable and adaptable to EVs fleet ➢ Better fault tolerance	➢ Accurate forecast and prediction of the user behavior of users are necessary ➢ Possibility for concurrent reactions

- **Charging System**

V2G involves two main types of charging systems: AC and DC charging systems. While the AC charger charges the battery via the on-board charger of the vehicle, the DC charger directly charges the battery of EV using an AC-DC converter on the charger side. An AC/ DC converter (or charger) is therefore always necessary. This converter can be located in the charging point ("**off-board charger**") or in the vehicle ("**on-board charger**"). The choice between off-board or on-board charger is a trade-off between the cost of the charging station (on-board is cheaper) and the vehicle (off-board chargers reduce the weight and cost for the converter in the vehicle). As availability of AC supply is prevalent, more locations are available for on-board EV charging.

The technical specifications for electric vehicle chargers vary across Level 1, Level 2, and Level 3 charging stations across different countries. Table below showcases the mapping of different charger specification in India:

S. No.	Charging Station	Voltage (V)	Power (kW)	Type of Vehicle	Type of compatible charger
1	Level 1 (AC)	240	<=3.5	4w, 3w, 2w	Type 1, Bharat AC-001
2	Level 1 (DC)	>=48	<=15	4w, 3w, 2w	Bharat DC-001
3	Level 2 (AC)	380-400	<=22	4w, 3w, 2w	Type 1, Type 2, GB/T, Bharat AC-001
4	Level 3 (AC)	200-1000	22 to 4.3	4w	Type 2
5	Level 3 (DC)	200-1000	Up to 400	4w	Type 2, CHAdeMO, CCS1,CCS2

For the AC charging stations, the Society of Automotive Engineers (SAE) has characterized the charging stations into two standard levels: Level 1 and Level 2. A **Level 1** electric vehicle supply equipment (EVSE) usually used in a residential charger utilizes the commonly available 240 V AC power from the grid in the current range of 12–16 A. Usually, a Level 1 charger requires about 11–20 h to completely charge an EV with a 16 kWh battery. On the other hand, a **Level 2** EVSE, which is primarily used in commercial spaces, such as malls and offices, uses three-phase 440 V AC power off the grid to power up to an electric current of 32 A and would require 3–8 h to fully charge an EV with a 16 kWh battery.

The DC charging stations (also known as Level 3 fast-charging stations) take AC power from the grid and through a power converter supply high-voltage DC power and a current of up to 400 A to charge the battery directly. This type of equipment circumvents the need for an on-board charger (OBC). As high voltage power is directly used to charge the vehicle, the time needed to charge is much lower (less than 30 min) to completely charge an EV with a 16 kWh battery.

The fast and ultra-fast charging may be a priority for the mobility sector. However, slow charging is better suited for smart charging than are fast and ultra-fast charging. Furthermore, fast and ultra-fast charging may increase the peak demand on the local grids when number of EVs are simultaneously in the charging state. Options, such as battery swapping, charging stations with buffer storage, and night EV fleet charging might become relevant in combination with fast and ultra-fast charging.

The main charging locations are at home, work and semi-public or public places. Most of the time, AC charging is implemented. At home, low power is usually sufficient (e.g., 3.7 kW on a 230 V circuit). The DC high-power charging is often deployed along highways, but some cities are also deploying it for street charging. For a 200 kWh battery, a charging power of 600 kW would be needed if the driver wanted to charge that quickly. With today's battery chemistry, a battery can charge at 3C (i.e., 20 minutes is needed to charge the battery from 0% to 100% if the same power level was kept). A 3C rate means that the discharge current will discharge the entire battery in 20 minutes. The C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity.

Therefore, the regulation in some countries/ regions encourages the inclusion of energy storage and local renewable energy (mainly solar PV) for fast-charging sites to reduce the costs and the need for capacity upgrades (e.g., through power purchase agreements for renewable energy for charging providers in some US states). However, the additional high capital costs of storage can limit the effectiveness of this technique to mitigate demand charges.

Few countries and cities including India have also mandated that a certain percentage of new or retrofitted parking spaces be "EV ready" through requirements in building codes. With zoning regulations, the cities can influence where and how many EV charging stations can be installed in each area. This is a key lever that can influence the availability of charging infrastructure in the future when the lack of multi-level dwelling and workplace charging could become a significant barrier to adoption and could restrict electrification of transport. Such measures have been already implemented in some regions of the US. For example, the California Green Building Standards Code of 2015 requires 6% of all parking spaces in commercial buildings to include infrastructure for EVs and has since been extended further. In Los Angeles, 240 V outlet and circuit capacity for Level 2 chargers is mandatory for every new building. Atlanta's new ordinance requires 20% of charging spots in commercial buildings to be EV ready as well as electrical infrastructures in new residential buildings to support EVs. Ontario, Canada requires 20% of parking in all new non-residential buildings to have full circuit capacity to support EV charging. The charging use case along with its impact and possible V2G opportunities are depicted below:

Charging use case	**Impacts**	**Possible V2G related Opportunities**
Home charging	Overloading issues may be expected for distribution transformer, feeder loading etc.	Off-peak charging or reduction of variable renewable energy curtailment via load shifting depending on connection time duration and charging time.
Workplace charging	Lower probability of overloading issues due to larger capacities typical in commercial or industrial zones.	• Potential increase of consumption of solar generation due to typical daytime connection. • Flexibility potential
Public roadside charging	Overloading issues may be expected for distribution transformer, feeder loading etc. especially with higher power draws from three-phase charging.	• Potential increase of consumption of RE generation due to typical daytime connection. • Flexibility potential
En route charging (Ex: Highways etc.)	Potential high-power draw. Depending on the power and volume required, dedicated transformer or stationary storage serving as a buffer might be required.	Limited demand response flexibility due to short or non-existent surplus connection time.
Depot charging	• Expected high-power draw due to larger volumes and numbers of vehicles served. • Dedicated substation might be needed, but the added cost can remain viable due to the nature of the commercial operation. • Network upgrades might encounter land use restrictions, especially if located in dense urban areas	• Fleet predictability and load management offer high potential for load shifting, variable renewable energy, curtailment reduction and bidirectional charging due to larger battery capacities and existing fleet control. • Flexibility potential might be limited to a few hours depending on the parking period and trip scheduling.
Battery swapping	• Limited overloading issues due to charging control	• 24/7 bidirectional interaction with the grid and the aggregated capacity could facilitate VRE. • Battery charging management can help reduce asset ageing.

- **Bi-Directional Charger**

V2G requires a bi-directional system to deliver electricity from the grid to batteries of EVs and vice versa. This bi-directional system can be facilitated using double uni-directional or single bi-directional converters. However, the utilization of double uni-directional converters (chargers) means a higher initial cost, heavier weight, and larger space requirements. Therefore, the bi-directional converters and the advanced development of solid-state technology has led to optimum techno-economic benefits. A bi-directional AC-DC converter facilitates both AC-DC power conversion and power factor correction. The EVs with bi-directional converters can achieve various features due to the nature of the power flow both from and to the grid. When the batteries of EVs are idle but still connected to the grid, they can provide energy to the grid when the demand is high, enhancing the grid efficiency. Also, bi-directional charging plays a key part in integrating RES with the grid. While bi-directional charging aids in voltage regulation, recurrent charging and discharging (cycling) of the battery causes battery degradation, which finally affects the battery life. Another issue with bi-directional charging is the additional cost involved with its infrastructure. Further, OEMs may explore the capabilities of V2G-enabled EVs in executing the reactive power compensation, leaving the EV batteries charged and at the same time *does not expose them to additional discharging–charging cycles*.

- **Communication System**

The communication between the grid and the EVs to transfer the data (e.g., SoC of battery, distance, etc.) and decide the charging mode results in a complex communication structure. The seamless communication among the EVs, Charging Stations and monitoring stations is a prerequisite to designing a charging stations network in an area. For achieving this, specific standards have been established, which have been set for EVs in four levels of the V2G technology: the plug, communication network scheme, charging topology, and safety standards. In V2G technology, both the data and the energy flow are bi-directional amongst the vehicles, charging stations, and power networks. As summarized below, ISO/ IEC 15110 standard establishes the standard for EV charging station communication, while the IEC 61850 standard establishes the standard charging station-grid communication as a result of which tariffs and charging are carried out effectively.

- **Indian/ International Standard related to EV charging system**

Brief Summary of Indian/International Standards related to EV charging system are as follows:

Standards	Selected Features
IS 17017	Electric vehicle charging standard in India
IS 17896	Electric Vehicle Battery Swap System
IEEE 1547	Interconnections to grid
ISO 15118	❖ Replacement for IEC 61851 or ISO 15118-2 ❖ Improved • Charging experience

	• Smart charging services • Grid services • Cyber-security ❖ Bidirectional power flow for • More RE uptake • Grid stability • Grid code support features
EN 50491-12	❖ Integration of EV into Energy Management Systems (EMS) ❖ Large-scale smart charging ❖ Improved interoperability
IEC 62196	Plugs, socket-outlets, vehicle couplers, and vehicle inlets—conductive charging of electric vehicles
IEC 61850-x	Communication networks and systems in substations
IEC 61439-5	Low-voltage switchgear and control gear assemblies, and assemblies for power distribution in public networks
IEC 61140	Protection against electric shock—common aspects for installation and equipment
IEC 62040	Uninterruptible power systems (UPS)
IEC 60529	Degrees of protection provided by enclosures
IEC 60364-7-722	Low voltage electrical installations, requirements for special installations, or locations—supply of EVs
ISO 6469-3	Electrically propelled road vehicles, safety specification, and protection of persons against electric shock
IEEE 2030.5	Enables utility management of the distributed energy resources such as electric vehicles through demand response, load control and time-of-day pricing
Open Charge Point Protocol (OCPP)	Open Charge Point Protocol, an application protocol for communication between EVSEs and a central management system, allowing charging stations and central management systems from different vendors to communicate with each other.
Open Charge Point Interface protocol (OCPI)	Supports information exchange between e-mobility service providers (e-MSPs) and charge point operators to enable automated roaming between charging networks for EV owners. Supported features include charge point information, charging session authorization, tariffs, reservation, roaming, and smart charging.
OpenADR	Open Automated Demand Response, a standardized demand response protocol that encompasses EV charging and DER programs, facilitating a common information exchange between utilities, aggregators, and customers. For V2G applications, the standard can be used between the EVSE and distributed energy resource (DER) management systems.
CHAdeMO/ Combined Charging System (CCS)	Charging standard for electric vehicles that enables communication between the EV and the charger.
IEC 63402 (under development phase)	International version of EN 50491-12

IEC 63119 (under development phase)	Alignment with other EV-related IEC standards.

- **Aggregator**

An aggregator must be able to participate in the electricity market through different ancillary services for the grid by organizing and optimizing the EVs charging and managing the load profile. In the first step of the process, the aggregator will establish a connection to each vehicle in the EV fleet, which has a service contract with the aggregator to utilize its battery, based on its current SoC to participate in ancillary services to the grid. The data from the EV will pass on the parameters required by the aggregator, with the condition for participation in the V2G system considering that the EV is sufficiently charged before the plug-out time. However, if the EV owner does not abide by the contract and drives away before the pre-notified departure time, the battery may not be sufficiently charged at time of the plug-out. Since the aggregator deals with thousands of vehicles at a time, the fraction of vehicles departing before the pre-notified time will remain constant and is negligible.

Further, the aggregator makes another contract with the grid operator, about the type of the service and regulation capacity to be provided to the grid or the power required by the aggregator to charge the EVs at a particular time, thus simplifying the task of the grid operator significantly.

- **System Operation and Optimization**

The power grid optimization has multiple objectives for smooth operation, but these objectives are riddled with many uncertainties and non-linearities having multiple constraints. Further, the dynamic and unpredictable nature of EVs could also increase the system complexity in the grid, which requires the demand optimization algorithm to utilize EV mobility to achieve V2G services, therefore, resource commitment becomes necessary to determine the optimal despatch schedule, and various optimization approaches are usually applied.

Another factor for consideration/ optimization for the charging stations is the location of the grid substations. It is essential to understand that the location of the charging station could be of interest to more than one sector, thus the decision of location of a charging station is multi-disciplinary in nature. From the point of view of the electricity sector, the location of the charging stations would be to minimize the investment, lessen the operations and maintenance charges, etc. However, the consideration of the location of the charging stations from traffic flow perspective could be different. Moving the location of a charging station away from an existing load center is beneficial from a grid perspective but is particularly undesirable from the consumer's perspective. Some of the primary considerations in planning the location of charging stations are to locate the station optimally in such a way that the EV drivers do not exceed their driving range while traveling from origin to destination. Thus planning the EV charging station at a desirable location to facilitate the adoption of the technology with only minor changes to their driving habit may be considered and optimized accordingly so as to avoid wasteful expenditure.

3. Expected benefits of V2G Technology in Transformation of Power Sector

➢ Optimized Grid Infrastructure Requirements

If high numbers of EVs were concentrated in certain geographical areas in an uncontrolled charging environment, the local grid would be affected by the congestion since charging load profile might match the existing load peaks and thus contribute to overloading of the transmission and distribution network which would warrant upgrades at the distribution and transmission levels. Additionally, this additional EV charging load would result in additional generation capacity requirements. With V2G smart infrastructure, such investments can largely be avoided by way complementing the EV charging load and the distribution load profile. Unlike the uncontrolled charging, it decreases simultaneity and lowers peaks in demand, thus would reduce the costs associated with reinforcing local electricity grids.

EVs typically spend about 80-90% of their lifetime in parking zone. These idle periods, combined with battery storage capacity, could make EVs an attractive flexibility solution for the power system. Each EV could effectively become a micro grid-connected storage unit with the potential to provide a broad range of services to the system. Further, V2G charging may not only mitigates EV caused demand peaks mainly at the local grid level, but also can adjust the load curve to integrate VRE.

➢ Flexibility in the Power System Operations

V2G charging of EVs could have impact on the integration of VRE, both in power system operation and in long-term network expansion plans.

❖ **System Flexibility due to EVs:**

- Peak-shaving in the grid
- Frequency control (primary, secondary and tertiary reserve)
- Other ancillary services (e.g., voltage management, emergency power during outages)

Peak-shaving: This involves flattening the peak demand and filling the “valley” of demand by incentivizing late morning/ afternoon charging in systems with large penetration of solar, and night time charging that could be adjusted following evening/ night time wind production, as cars are parked for a longer time than they need to fully charge. Early evening charging that may otherwise increase peak demand would be deferred in this way. Consequently, this would defer investments for building additional peak capacity.

Ancillary services: This involves supporting the real-time balancing of grids by adjusting the EV charging levels to maintain steady voltage and frequency. While the flexibility has been well-developed at the transmission system level, distribution system level are mostly not yet equipped with flexibility from distributed energy resources for operation.

❖ **Local Flexibility:**

- Voltage control
- Local congestion and capacity management
- Increasing the rate of Renewable Energy self-consumption
- Arbitrage between locally produced electricity and electricity from the grid
- Back-up power

Optimization and back-up power: This includes increasing self-consumption of locally produced renewable electricity as well as lowering dependence on the electricity grid and reducing the energy bill by buying low-cost electricity from the grid at off-peak hours and using it to supply homes when the electricity tariff is higher (during evenings). In addition, the EV battery can be used after it has been removed from the vehicle. An EV battery usually be replaced when the capacity declines to 70–80% (that is, when it may no longer be sufficient for daily mileage); however, the performance is still sufficient for energy storage systems. This may offer a lifetime extension of the battery. With increasing penetration of the EVs, the number of potentially available *second use batteries* would increase. Acting as stationary storage appliances after being removed from the vehicles, the batteries can further contribute to power system support.

➢ **V2G-Facilitated Resilience Contribution in areas prone to natural disasters**

In areas prone due to extreme weather events, such as cyclones, floods etc., enabling EVs as mobile power units could be particularly useful in enhancing resilience in these areas. In this respect, V2G may provide power back to the grid or to specific buildings, such as emergency shelters, hospitals, other critical facilities, or an entire neighborhood during power outages.

4. Key factors for Enabling V2G:

➢ **EV charging Provision by Government/ Government Agencies**

❖ **Ministry of Power (MoP) targets for public charging**

Issued the "Guidelines and Standards for Charging Infrastructure for Electric Vehicles" in 2018, amended in 2019. Salient points of the guidelines are:

- Bureau of Energy Efficiency is the central nodal agency (CNA) for all public EV charging infrastructure.
- State governments need to appoint state nodal agencies (SNA) for setting up public charging infrastructure.

- Provision of guidelines and requirements (including charger types, electrical infrastructure requirements, testing and certification, and phased rollout) for public charging infrastructure.
- Electric vehicle charging equipment to be tested by any lab/facility accredited by National Accreditation Board for Testing and Calibration Laboratory (NABL).
- No license required for operating EV charging stations.
- Notification for setting maximum tariff for private charging at residences and offices, tariff not to be more than average cost of supply plus 15 percent.

In its Charging Infrastructure Guidelines and Standards, the MoP also provides the following minimum requirements for the location of public charging stations:

- At least one charging station should be available in a grid of 3km x 3km.
- One charging station to be set up every 25km on both sides of highways/roads.

As per MoP guidelines, the public charging stations may contain one or more, or any combination, connector types etc. Charging stations for e-2Ws and e-3Ws can install any charger, provided they adhere to technical and safety standards laid down by the Central Electricity Authority (CEA).

❖ MoHUA targets for semi-public charging

The Ministry of Housing and Urban Affairs (MoHUA) amended its Model Building Byelaws (MBBL), 2016 to include the provision of EV charging in buildings. The amendments have been made in Chapter 10 (Sustainability and Green Provisions) of the MBBL, 2016, with Section 10.4 titled “Electric Vehicle Charging Infrastructure”.

- Charging infrastructure shall be provided for EVs at 20% of all ‘vehicle holding capacity’/ ‘parking capacity’ at the premises.
- The building premises will have to have an additional power load, equivalent to the power required for all charging points to be operated simultaneously, with a safety factor of 1.25.

The amendments are applicable to all buildings except independent residences. Further, provision norms for slow chargers (SCs) are provided based on the number of EVs to be serviced, by segment. Norms for fast chargers (FCs) are not compulsory.

Provision Norms For Charging Points	**4Ws**	**3Ws**	**2Ws**	**Buses**
	1 SC per 3 EVs 1 FC per 10 EVs	1 SC per 2 EVs	1 SC per 2 EVs	1 FC per 10 EVs

However, the States/ UTs have the power to adopt and enforce amendments to building byelaws, through urban development authorities or municipal corporations. With buildings typically having a lifespan of 50 years or more, States/ UTs are recommended to adopt the EV charging infrastructure amendments at the earliest to ensure that all new constructions are EV-ready.

❖ Government of NCT of Delhi mandates 5% parking for EV charging

In March 2021, the Government of NCT of Delhi directed all commercial and institutional buildings with a parking capacity of more than 100 vehicles to set aside 5% of their parking spaces for EV charging. This includes shopping malls, hospitals, hotels, offices, educational institutions, movie theaters, etc. Properties will be required to set up slow EV chargers (at a minimum) at the reserved parking spots, and will be able to avail of a subsidy of INR 6,000 per charging point, as provided by the Delhi EV Policy.

➢ Charging Infrastructure

Slow chargers – are mostly used for home and office charging. With slow charging, the EV battery is connected to the grid for longer periods of time, increasing the possibility of providing flexibility services to the power system. Long-duration charging may provide the flexibility in the power system as most of the charging takes place at home during the evening, and at night and at the workplace during the day.

Medium-duration (typically 30 minutes to 2 hours) chargers - at shopping or leisure centres (movie theatre, gym, etc.) or short-duration (15 minutes to 1 hour) charging provide minimum flexibility for the system and may be less suited for grid services.

Fast charging – on the highways is rather exceptional today as EVs are not yet used for long trips mainly due to the limited range issue and the lack of appropriate charging infrastructure. Fast and ultra-fast charging does not leave batteries connected to the system long enough to provide flexibility. The impact of fast charging on the grid will need to be mitigated by installing charging points in areas that have a low impact on local peak demand and congestion. Also, combining fast-charging infrastructure with locally installed VRE and stationary energy storage can, through buffering, increase the flexibility of the station vis-à-vis the grid.

In light of the above, it is to be observed that slow charging is best suited for the "smart" approach that boosts the power system flexibility. But solutions like battery swapping, charging stations with buffer storage, and night time charging for EV fleets can help to in mitigating the peak-demand stress from fast and ultra-fast charging, reinforcing the local electricity grids. Unlike uncontrolled charging, it decreases simultaneity and lowers peaks in demand.

➢ Roles and responsibilities of the Stakeholders

One of the important characteristic of the smart charging is being at the junction between the electricity market and e-mobility. Unlike “traditional” charging, where the e-mobility market (EV drivers, charging point operators, mobile service providers) acts independently of the electricity market, the smart charging requires a close co-ordination between the two in order to both accommodate e-mobility requirements in the power system and provide the power system with the needed flexibility.

➢ Regulatory priorities

To make V2G successful, there is a need to the stack revenues from multiple revenue streams, providing flexibility at both the system and local levels. The key regulatory aspects that are needed include implementing, initially, time-of-use tariffs (i.e. increase the price differential between the peak and the off-peak is, the more effective the rate design is. The setting of the peak and off-peak (or even “super off-peak”) corresponds to the characteristics of the local electricity system. In most cases, the drivers can pre-set the charging for off-peak hours through an app or the on-board system of the vehicle and then the dynamic prices for EV charging would allow the EVs to participate in ancillary service markets which would enable revenue stacking.

First, the appropriate price signal is a key enabler for the implementation of V2G, because the price signals to EV users would make it possible to shift the demand for EV charging to off-peak periods and to match it with the availability of renewable energy sources. Increasing automation would enable both drivers and service providers to manage this system. For example: Several retailers, mainly in the United States, have adopted EV home charging tariffs, offering charging rates up to 95% lower at night compared to during the day.

Second, having a single revenue stream would be insufficient to make a business case for V2G. In other words, the batteries will have to “stack” the revenue by serving multiple applications, providing services to both system level and locally.

The policies and regulations should allow EV batteries to provide different services to the power system, encouraging stacking of services and revenues. But multiple levies for V2G need to be avoided as this would make the grid support by EVs non-remunerative. The charges should be applied only to the net energy transferred for the purpose of driving.

- **Business models**

The business models need to account for the requirements of the power system such as remuneration for providing ancillary services to power systems and the vehicle owner – by providing mobility and preserving the condition of the vehicle and the battery. The parameters such as speed of charging, the health of EV batteries, the potential reduced battery lifetimes and others must therefore be monitored. These should be taken into account when determining the V2G charging business models.

Few examples:

1. Providing operation services would require the battery to act “on call” while receiving stable revenues just for being available. On the other hand, the electricity price arbitrage requires repetitive charging and discharging, which greatly reduces the battery life.
2. EV batteries can provide the fast response needed for some ancillary services, but their power capacity is limited; thus a single EV cannot provide these services for the period of time needed by the power system. However, when EVs are aggregated they can complement one other, resulting in a virtual power plant with a fast response and the ability to provide services for the needed period of time. The aggregator business models may facilitate the use of EVs as a source of flexibility. At least 1-2 MW capacity must be traded to make EV power provision viable in the market. This requires the aggregation of around 500 vehicles approximately along with charging points.

The smart charging following renewable energy generation patterns needs to be incentivized by appropriate market design and automated control. Possible EV Revenue Streams may be:

(a) Direct benefit
(b) Services sold via aggregator:
  - At transmission system level: Fast Frequency reserves; Primary reserves; Secondary reserves
  - At Distribution system level: Congestion management via load shifting/peak shaving; Voltage control

➢ Batteries Capabilities regarding Grid Balancing Services

Key technical terms for classifying battery technologies:

- End of Life (EoL): is the moment when the battery retains only a fraction (typically 70%) of its initial capacity. It is expressed as a percentage of initial capacity.
- Depth of discharge (DoD): is the percentage (compared to full capacity) to which the battery can be discharged.
- State of charge (SoC): is the capacity of the battery expressed as a percentage of the full capacity at which the battery is during usage charge.
- Cycling rate (C-rate): is the rate of charge or discharge. 1 C refers to a charge or discharge in 1 hour, 2 C refers to 2 hours, and 0.5 C refers to 30 minutes.

EV battery capacity and technical characteristics determine the extent to which cars support the renewable energy sources integration. Today, most of the EVs are having lithium-ion batteries. The cost reductions coupled with battery performance improvements and suitability for grid applications makes this technology a worthy choice.

The EV battery capabilities to provide specific grid services are key in this context, setting aside their impact on the vehicle’s performance. Capabilities to provide services to the grid and corresponding technologies will depend on the considered application. For example, for balancing RE, high depth of discharge tolerance, i.e., the extent to which the battery can be discharged is necessary. A large number of full charging cycles per year (typically around 300) is necessary for a battery to provide system-wide balancing variability in renewable generation. A high depth of discharge (DoD) tolerance is required. All types of lithium-ion batteries are the best suited today. However, redox flow battery technology, with its long cycle life, is able to undergo high DoD and can provide this service. For ancillary services, lower depth of discharge is required. Since batteries must be able to inject power when frequency is low and also to consume power when frequency is high, the ideal standby state of charge is approximately 50%, which means that the selected batteries should be able to work at lower state of charge.

Ancillary services are used to balance the electricity grid i.e., to keep the grid frequency around the reference. These services can be divided into primary reserve, secondary reserve and tertiary reserve:

- **For primary reserve**, DoD and battery involvement is smoother than for renewables balancing. When the frequency drops, the battery must inject power and vice versa. To do so, the referenced battery state of charge remains around 50% and will fluctuate in a narrow band around this level.

- **For secondary reserve**, the reaction time needed is slower and the amount of cycles required is lower.
- **For tertiary reserve**, the reaction time needed is slower and the number of cycles required is lower. The energy needed is higher.

Li-ion batteries can compete with other technologies used for stationary storage such as lead acid and redox flow batteries. Battery degradation from increasing the number of charge/ discharge cycles has been a long-debated issue with respect to V2G and battery swapping. Battery degradation is affected mainly by the discharge current, the depth of discharge and the temperature of operation. But the recent studies have shown that battery degradation with V2G is limited if the battery stays within a state of charge of around 60-80%. The impact is similar to normal AC charging.

Application	**Renewable storage**	**Ancillary services**		**Back up**		
Battery acceptance	**High DoD**	**50%SoC**	**Low DoD**	**Low C-rate**	**Long standby at high SoC**	**70%DoD**
Li-ion	✓	✓	✓	✓	x	✓
Lead Acid	x	✓	✓	✓	✓	✓
Redox Flow	✓	✓	✓	✓	x	✓

Note: DoD (Depth of discharge), SoC (State of charge), C-rate (Cycling rate)

Battery chemistry evolution would affect not only mobility aspects such as driving range but also the speed of charging (also related to grid infrastructure reinforcement needs) and the ability of batteries to provide grid services. Despite high energy density and suitability for both mobility and grid applications, Li-ion technology has limitations in terms of safety as well as related potential cost impacts. Improving the safety parameters of any Li-ion sub-chemistry would in turn lead to deteriorated performance in particular energy density. Li-ion batteries would age more quickly in charged state (not stable) compared to lead-acid batteries. To use Li-ion for back-up for a long time, the battery would have to be kept partially charged, not completely charged, to keep the chemistry stable and to prevent any runaway or drastic capacity decrease thus using the battery at only a portion of its capabilities. Even though lead-acid does not perform cycling, it can be maintained at a high state of charge for a long time without ageing. A number of technical challenges would need to be overcome to maintain the grid-related capabilities with these technologies.

➢ Second-life Storage Applications

An alternative to recycling of used EV batteries is reconditioning them and reusing them in stationary applications. The second-life battery solutions could also provide energy storage services. An EV battery needs to be replaced when the capacity declines to 70-80% that is when it is no longer sufficient for daily mileage but is still in good condition to be used as an energy storage system.

- **Harnessing Synergies between EVs and Solar & Wind Power**

By way of smart charging infrastructure, when many cars are trying to charge at the same time, the system rotates them to allocate capacity. This system makes it possible to charge all the EVs by distributing the available power across all the vehicles and charging them in sequence, without overloading the local feeders. Network reinforcement would be required when power is insufficient to charge all the vehicles (e.g., overnight). With the adoption of EVs, V2G strategies could be synched with RE sources to not only minimise the impact of extra load on the power system, but also harness the synergies between EVs and renewables in the system.

EV fleets can create vast electricity storage capacity. However, optimal charging patterns would depend on the precise energy mix. EV integration differs in systems with high shares of solar-based generation compared with systems where wind power prevails. If synergies established, the use of EVs as a flexibility resource via smart charging approaches would reduce the need for investment in flexible, carbon-intensive, fossil-fuel power plants to balance RE.

While EVs do not release emissions when driven, they use electricity that often comes largely from fossil fuels. To reap the full benefits of both, the electrification of transport must go hand in hand with de-carbonisation of the power sector. The examples in this respect made by the countries of Japan and Sweden are worth to mention. Sweden’s entire VRE generation comes from wind whereas Japan´s comes from solar. In this sense, Japan could use its 26 GW of pumped storage hydro to store excess solar PV during the day, and then use that electricity to charge the EVs at night. However, in the Swedish case, the charging of EVs could be more spread throughout the day and night to match the availability profiles of wind.

The incremental benefits of V2G will be particularly significant in solar-based systems. By shifting charging to better coincide with solar PV generation, and by implementing V2G, increased shares of solar could be integrated at the system level and the local grid level, mitigating the need for investments in the distribution grid. For EV charging to complement solar, the charging must shift to mid-day, which also means that charging stations must be located at workplaces and other commercial premises where EV owners park their vehicles during the day. For that, pre-cabling and smart chargers should be promoted at commercial buildings.

Wind production profiles are more region specific. In some regions, these profiles may match well with EV charging profiles, even if EVs are charged in an uncontrolled way, because wind may blow more in the evening and at night when EVs are connected for charging. In such systems, the focus should be mainly on the home charging at night and on adjusting dynamically to variations in wind production.

The smart charging provides benefits in the systems having high solar PV than wind, due to the more predictable generation profile from solar. The incremental benefits of smart charging in terms of impact on renewable capacity could thus be high with solar, mainly with the use of affordable batteries that can store excess renewable power that is not consumed during the day, and then despatch this power later. In this respect, workplace and commercial charging would be key for ‘solar-based systems’ preferably. The potential synergies between home charging for ‘wind-based systems’, combined with home solar needs to be explored.

- **Information and Communications Technology (ICT) Control & Communication Protocols**

In order to optimize the charging infrastructure vis-à-vis local grid system and facilitate information sharing, communication protocols need to be developed. V2G charging involves the charging of an EV controlled by bi-directional communication between two or more actors to optimize all customer requirements, as well as grid management, and energy production including renewables with respect to system costs, reliability, security safety and limitations, if any.

The communication protocols so developed need to be standardized, while V2G charging stations and control systems need to be made interoperable, i.e., interoperability between EVs and supply equipment. There is a need that these protocols allow for connecting the central system with any charge point, regardless of the Charging Point Operators (CPOs). The control mechanism can be enabled by the grid, the charging point or the vehicle itself. Further, a communication system with the grid allows the charging process to take into account actual grid capabilities and conditions as well as customer preferences for charging and discharging options. The price or control signals can be communicated through an Information and Communications Technology (ICT) infrastructure, for example, intelligent metering system, communication between charging stations and back-end systems, in order to allow algorithms to take into consideration generation and grid constraints, as well as to enable customers to benefit from price opportunities and charging station information to provide a continuous forecast of the available capacity.

- **The Role of DISCOMs**

The distribution companies (DISCOMs) are responsible for providing electricity connections for the EV charging infrastructure, implementing the EV tariff structure approved by the SERCs/ JERCs, ensuring that EV charging infrastructure is connected and operated and maintained properly, preventing improper use of EV charging infrastructure, managing the distribution network, and undertaking grid upgrades based on growth in load including from EV charging requirements.

The DISCOMs should conduct assessments of EV charging requirements at the grid and feeder levels for different scenarios of EV penetration, with other factors of interest such as spatial concentration of EVs, differential EV charging patterns, and the model impacts of Time-of-Use/ Time-of-Day (ToD) measures. Subsequently, the DISCOMs should develop EV readiness plans based on charging load impacts on the grid infrastructure. This would help the DISCOMs devise their load management strategies, develop grid upgrade plans, and plan for additional procurement of additional power, if needed.

Role of Charging Point Operators (CPOs) and e-mobility service providers (e-MSPs)

The Charging Point Operators (CPOs) and e-mobility service providers (e-MSPs) manage and enable day-to-day operations of EV charging infrastructure. The CPOs and e-MSPs are also responsible for setting up the framework architecture, protocols, and processes to enable centralized management of charging facilities and their communication with the DISCOMs, and ensure efficient access to EV charging services for the customers.

The DISCOMS (public or private) are also entering the charging infrastructure market as CPOs. These utilities typically use their own land to set up public EV charging facilities and operate them as paid services. The DISCOMs may also provide bundled charging services for private EV owners, and recover the capital and operating costs through electricity tariffs. Other stakeholders driving the service provider model of EV charging implementation include companies/ start-ups that are moving into charging infrastructure, and EV manufacturers who are setting up charging infrastructure networks as allied services.

Digitalization

The digitalization would eventually help to break silos between power and charging infrastructure by facilitating smart charging. Once high EV penetration is reached, the forecast availability of flexibility in the grid needs to be modified based on the preferences of the individual driver. There is need for an incentive for the user to plug in as much as possible to exploit the full potential of flexibility in grid support. The individual customers participating in smart charging would have to be ensured that a sufficiently charged vehicle is always available them for their commute. Also, the charging habits would not be homogeneous due to difference in the sensitivity to price, travel habits, access to parking, attitudes towards re-charging and perceptions to different EV charging options.

The digitalization would inform customers and empower them by encouraging appropriate price signals in all geographies. The dynamic pricing may send signal to the EV owners about the best time to charge and discharge. Highly digitized environment would enable both the drivers and service providers to manage the ecosystem well.

Artificial Intelligence and Big data

The smart charging through use of V2G integration technologies is a means of managing EV loads, either by customer response to price signals or by an automated response to the control signals as per the grid conditions, or a combination of the two, while respecting the customer’s needs for vehicle availability. It consists of shifting some charging cycles in time or modulating the power in function of some constraints, for example, the connection capacity, user needs, real-time local energy production. The advancements in the big data and artificial intelligence could facilitate and optimize the services provided by smart charging solutions. The ICT advancements including data management and data analytics from drivers, charging patterns, and charging stations would enhance smart charging functionalities and automise the services required to the grid. In addition, the digital technologies and data analytics would enable the mobility demand with power supply patterns to be as compatible as possible and to decide about the most optimal locations for charging points. If direct control mechanisms enabled by the EV and the charging point are in place, further services could be provided to the grid without affecting consumers' needs. For instance, the customers could set the car's departure time and / or the required battery capacity reserve. The charging station then determines the current battery status and calculates the energy necessary to reach the desired state in the most optimal way to improve the power system's economic and environmental performance.

The use of digital tools may help in enhancing the acceptance of EVs for V2G by the customers including lessening the market complexity while interacting with the grid to increase the renewable energy shares. For example, a smart charging system may enable automatic charging of EVs when energy cost is lower.

- **V2G in Island Systems**

  The islands away far from the mainland are often dependent on fossil fuels, in particular, petroleum-derived fuels representing a major share of the total primary energy use as the inclusion of traditional sources is limited, for their energy needs. While each isolated system is different in terms of weather, population and economic activity, the response to power system shocks in island regions is generally demanding, i.e. the loss of a few electricity supply units has a bigger impact than in interconnected systems, and the effects of voltage/ frequency drops are very significant. As a result, balancing the grid is more onerous and the risk of load shedding and brown outs/ black-outs is frequent requiring additional generation reserves. Introducing VRE for meeting the carbon neutrality goals is challenging from the system stability point of view.

  The typical electricity consumption of an EV driving 15,000 km/year is about 3,000 kWh/ year. Even with slow charging, i.e., charging with low power, say 3.7 kW, the total idle time would be about 15% of the total time required for charging the EVs on yearly basis. Supposing that an EV is connected to charging infrastructure 100% of its parking time, this means that the yearly "flexibility window" for charging represents about 85% of the time. Theoretically, this would translate into a flexible energy output of about 3000 kWh/ year per car. In other words, EVs can be charged in a fraction of their parking time. Incentivizing charging at times when electricity is the cheapest represents a significant opportunity for the power system and for EV owners.

- **Standardization** also will facilitate the spread of V2G technology which currently has an interface cost approximately 3-5 times higher than that of unidirectional smart charging.

- **Battery Swapping**

  The redundant battery storage at the stations or battery swapping with supplementary battery storage that can draw power from the grid at the most optimal time and then use it to charge EV batteries could complement grid balancing.

  A major issue when it comes to higher penetration of EVs is their initial cost, of which around 50% is attributed to the battery packs in EVs. The battery swapping can also overcome this hurdle if an ideal scenario of pay-as-you-go model is adopted, where a third party holds ownership of the batteries and manage their charging requirements. In this case, Battery Swapping Stations (BSSs) are needed which adds to the infrastructural costs. A topology of BSS, along with a battery sharing network, may interact with each other using Internet-of-Things (IoT), thereby acting as an aggregator and providing services as a whole to the grid, such as enhancing grid stability and reliability in the process. Even if the infrastructural cost associated with this topology is kept aside, the idea of owning a car without the battery and having no guarantee for the State of Charge of the battery that is swapped can operate as a social barrier from the viewpoint of the customer. Some of the barriers in respect of battery swapping are mentioned below as:

- Lack of standardization among EV batteries
- Unsuitable battery pack design to enable ease of swapping (weight, dimensions etc.)
- Shorter commercial life of battery packs due to customer preference for new batteries with higher range.
- Slow adoption of charging method by OEMs.
- Higher costs of battery leasing over the life of the EV

At present, battery swapping may be considered feasible solution for commercial EV fleets, especially in the EV (2 W & 3 W segments). As robotic swapping is used for 4W and Electric buses for swapping batteries due to larger and heavier batteries requiring mechanical assistance. These swapping stations are also expensive and require bigger piece of land.

The Ministry of Road Transport and Highways (MoRTH) has allowed the sale and registration of EVs without batteries, which provides a huge boost to battery swapping solutions. Further, the industry stakeholders are making large investments in developing the battery swapping ecosystem. This indicates that battery swapping would emerge as a distinct part of EV charging networks in India in the coming years.

- **Interaction with the vehicle owner** is key, including the **forecasting** of use in terms of schedule and driving distance.

5. Implementation Requirements

Technical Requirements	**Hardware:** • Widespread adoption of EVs. • Public and private charging infrastructure – smart charging points. • Smart meters – required for supplying interval values for net consumption and net production
	Software: • Smart charging services such as energy and power flow management systems that allow for optimal EV charging, ICT systems, intelligent charging infrastructure or advanced algorithms for local integration with distributed energy sources.
	ICT structure and development of communication protocols:

	• Develop common interoperable standards (both at physical and ICT layers). • Develop a uniform solution for the method of communication between charge points and the central power system, regardless of the vendor.
Regulatory Requirements	**Electricity Market:** • Allow EVs, through aggregators or individually, to provide services in the ancillary service market and wholesale market. • Enable revenue streams to incentivize smart charging of EVs. • Efficient price signals (such as time-of-use tariffs) or other load management schemes to incentivize smart charging. • Understand customer behavior and create awareness of the possibilities to use load management.

6. Challenges

➢ Impact on grid infrastructure

As outlines earlier, the EV charging would have an impact on the grid investments. The scope of grid investments in terms of cables/ wires and transformers that would require to be made in a given location would depend on the following parameters:

- **Congestion:** such as in the local distribution network prior to any EV deployment. The failure to distribute the EV charging locations increases congestion in the distribution grid congestion thus leading to grid asset ageing and service interruptions. Both of these challenges have potential to increase the cost of electricity supply, create inconveniences for EV charging and ultimately increase the cost of EV ownership.
- **Load characteristics:** for example, the impact of uncontrolled EV charging would be higher in locations with high shares of electric heating thus leading to higher grid reinforcement. As the EV fleet size increases, the failure to manage EV charging may lead to an increase in peak demand and cause operational challenges for the grid. If EVs were charged simultaneously in an uncontrolled way they could increase the peak demand on the grid, contributing to overloading and the need for upgrades. The extra load may even result in the need for additional generation capacity
- **Generation assets connected at low voltage level:** for example, integration of high shares of solar PV connected at low voltage level (for example, in Germany) could be facilitated with smart charging, whereas in locations with no or very low shares of solar PV, EVs could increase the strain on local grids.
- **Grid Code limits and other regulations:** for example, national grid codes define physical constraints in terms of both voltage and frequency variations that grid operators have to respect, and investment in grid reinforcement if these country-specific limits are exceeded due to EV charging.
- **Voltage imbalance and Power Quality issues**: Residential loads in the distribution network are mostly connected at low voltage levels. Residential EV charging too is mainly connected to the LV distribution network, which brings another set of challenges. Based on the line resistance and reactance, each bus has a critical voltage where the active power is the highest. The ratio of change in voltage due to change in active power is termed as Voltage Sensitivity Factor (VSF). A high VSF means that even for small changes in active power, there is a significant drop in voltage and vice

versa. EV charging stations introduce large active power demand from the network, and the consumption of power is significantly higher for fast chargers compared to slow chargers. So, an Electric Vehicle Charging Station (EVCS) installed in a bus with high VSF will significantly degrade the voltage at the point of connection. Voltage unbalance issues can also come up due to unequal loading of the three phases. In case of EV charging, if the single phase chargers are not equally distributed among the three phases, voltage imbalances may occur. Further as these EV chargers are power electronic devices so they also inject harmonics into the system. Hence, the challenge would be to keep harmonics within the limits.

- **Less compatibility of Mobility-as-a-service with EV based flexibility**

Car sharing and carpooling are already changing the habits of the customers. Moving away from vehicle ownership to shared mobility and to Mobility-as-a-Service (MaaS) is expected to continue progressively with digitalization. Further, the increased daily distances travelled per car would imply reduce parking time i.e., less battery capacity available for the grid support services. Consequently, the net available flexibility in the system might decrease, especially during the daytime, for balancing solar power. The implications for the availability of EV flexibility which may decrease in a future system based on shared vehicles compared to a transport system based on individual EV ownership needs to be studied in detail. MaaS could work against VRE integration, as fewer EV batteries connect to the grid.

Studies have shown that “ride-sharing” could lead to an increase in the number of kilometres. Nevertheless, downwards pressure on available flexibility is likely to occur under this scenario, as:

- Distance travelled by individual cars would increase, reducing the amount of time that they are idle and connected to the grid.
- Zones of strain on the local power grid can be created once charging is focused in hubs. These hubs may be relevant for centralised flexibility management in the night but still probably lower than with individual car ownership, as transport service optimization will aim at maximum usage. Vehicle fleets would have to be steered towards an optimised fleet charging and routing, contributing to the goals of EV grid integration and optimised renewable energy use.

- **Fast charging**

Fast charging represents a challenge for grid infrastructure. The higher the power, the more capacity is required from the grid. In addition, the locally deployed charging station/ cables and vehicle must support this power. Both of those are technologically feasible but come at a price:

- Vehicles require more expensive electronics and protection devices.
- Grid connection of fast-charging stations requires bigger cables and transformers.
- Such charging stations require more expensive electronics and cooling as well as protecting devices.
- Active cooling of the charging cable is needed if very heavy duty cables are to be avoided. Increasing voltage level of supply may mitigate the need for heavier cable and/or active cooling, but this may not be an optimal solution considering the interoperability with the existing infrastructure and with the existing EVs).

- Fast charging applications generally have low potential for VGI even though it is technically possible. When fast charging is needed, there is no real flexibility option due to short charging time. Further the peak load at highway stations may not coincide with conventional peak load. The impact of fast charging on the grid would need to be mitigated by installing charging points in areas with low impact on local peak demand and congestion while achieving a high utilization rate (for profitability).

➢ Batteries Capacity

Depending on the geography and specifically the access to a private parking space at the residential level, the proportions among the charging locations might differ. In less densely populated areas, most of the charging cycles are performed at home or at work. In densely populated cities with no charging points at home or at work, a larger proportion of the charging could be done in public places in the city. Large parking spaces or bus depots have more technical opportunities and incentives to contribute to energy flexibility than do disperse charging locations. However, most charging is done at home and at the office today due to individual ownership of vehicles and to the low cost of charging this way. How much battery capacity can be made available for smart charging depends on the vehicle's battery capacity and on drivers' needs.

Typical Battery Specifications for Different EV Segments used in India are as follows:

EV Segment	Battery Capacity	Battery Voltage
2 w	1.2-3.3 kWh	48-72 V
3 w	3.6-8 kWh	48-60 V
4 w (1st gen)	21 kWh	72 V
4 w (2nd gen)	30-80 kWh	350-500 V

- The battery Capacity: electric 2-3 wheelers will offer less energy flexibility than premium cars with bigger batteries.
- Sufficient State of Charge i.e., the available capacity of the battery at time of departure may be guaranteed. At the moment of disconnection, the battery should have a state of charge that meets the driver's requested range (typically at 70-80%) so that the car can still provide sufficient range. However, the importance of this parameter will decrease with EVs having larger batteries, and with higher penetration levels for charging stations. Bigger batteries helping to overcome range anxiety, there will be more EVs with larger batteries connected to the grid.

Parameters such as speed of charging, the health of EV batteries, potential reduced battery lifetimes and others must therefore be monitored. For example, providing operation services would require the battery to act "on call" while providing stable revenues just for being available. On the other hand, electricity price arbitrage requires repetitive charge and discharge, which greatly reduces the battery life.

➢ Deterioration in Life Cycle of the Batteries

Battery degradation would be an issue with V2G technology, as the frequent charging and discharging cycles of the battery induced by the nature of the V2G infrastructure might degrade the battery life span. This would have a huge impact on the viability of the business models that pin on the V2G technology and affect the social acceptance of the technology. Battery degradation is primarily dependent on two factors: *calendar aging* and *cycling aging*. While the former is dependent on temperature and SoC, the latter is dependent on the depth of discharge and power throughput. Recent research shows that V2G, if used without proper management, may lead to significant battery life reduction, which would be the case when, for example, peak shaving services are used daily.

- **Charging Pattern**

  The charging patterns of shared and commercial cars e.g., taxi and other car fleets, etc. may be less predictable, depending on the business models. Nevertheless, the transport service revenue is critical and the time of standing still should be reduced to a minimum, leading to smaller time with grid connection and higher charging power, compared to individual cars. While cargo transport may occur mainly during the night, commercial services like taxis still have higher demand during the day.

  The duration for which EV is connected to the grid depends on the immobilization time, which is determined by the type of vehicle, its use and charging time. Taxis or buses that travel to and fro would have less immobilization time and therefore less flexibility than single EV used by individuals. While an electric bus or truck may use 100% or more of battery capacity every day, passenger cars and two-wheelers may use 40% to 50% of it. Further, when and where the vehicle is charged also depends on the car type, its use, the geography and the availability of the infrastructure. The factors determining the amount of available flexibility from a single EV:

    - HOW LONG: Standing idle and “plugged in”
    - WHEN: Time of day
    - WHERE: Charging location
    - WHAT: Charging technology/power level
    - HOW MUCH: Battery capacity and desired state of charge at departure

- **Profitability and competitiveness of EV flexibility** with other flexible sources at the power system level remains a key issue due to following factors:
    - The price spreads in the system may be lowered.
    - The revenues from ancillary services may not provide sufficient flexibility in all markets.
    - EVs would compete with other types of decentralized flexibility such as demand-response resources, and with the used EV batteries themselves.
    - The EV case may be more powerful at the local grid level, leading to potential minimalisation of low and medium voltage grid extension requirements. However, this potential business case would need to be monetized for EV drivers and service providers.

- As standardization progresses and as the requirements for better control of the charging power increase, the vehicles and charging points would have smart charging options including discharging as a common feature provided by auto manufacturers/ OEMs, and technically enabling provision of ancillary services to the grid.

➢ **Cyber-security**

V2G technology requires a certain level of cyber-security for seamless operation and to ensure grid security, since the digital grid handles massive amounts of data, making V2G a perfect target for cyber-attacks. Thus, network security and integrity with data transmission in the grid becomes essential for the seamless, safe and secure data transfer from EVs to the grid.

7. Stakeholder Inputs

Utility	Inputs	Concerns
Tata Power	(i) V2G is possible only when the vehicle is connected to Charger. In general Vehicle is predominantly connected to charger at his premise especially during night time and at public places it is intermittently connected while there is a requirement of charging. So a major application of V2G would be supporting Grid during Night Peak load especially during summer where the Air conditioning load would be predominant between21 hrs to 24 hrs. (ii) Majority EV sold in India has a battery capacity ranging from 25KWh to 50KWH capacity. Average running km per day is about 40-60 Km/day. Remaining SOC available aftera day would be around 60-70%. (iii) In general being a slow charger we can draw only minimum power of 3.3KW or 6.6 KW for a period of 2-3 hrs where it can support the grid thereby reducing the SOC by20-30% and thereafter the charging of the battery could happen. (iv) In order to enable V2G feature the first requirement would be enhancing the features of the following: **a. Home charger:** • As per prevailing scenario more than 50,000 no's of home charging were being installed by TATA power to support EV OEMs. • Current prevailing ratings are 3.3KW,	**Role of Electric Utility:** **(i)** Peak load management is one of the critical scenario of the power distribution utility through proper means. To manage the Power flow through Batteries of EV there should be an integration of signal between the chargers and Utility control centre. There should be a policy direction for sharing the controls between the various service providers. **(ii)** Generally now for conducting a Demand response program, the consumer consent is obtained in advance and during that duration the non- essential loads are being trimmed. In similar front when such requirement is needed, the EV bus depot consent to be established first and necessary control to be enabled from the back end

		6.6KW, 11KW AC chargers are being used. • As far as 3.3KW chargers is concerned it is mere a plug and socket arrangement with ELCB control. Here the consumer uses the cable arrangement provided by EV OEM where the one end simple AC plug in inserted in to the socket and the other side charging gun of Type-2 is inserted in to the vehicle. Here the AC to DC conversion happens inside the EV where the Vehicle has an onboard chargers of 3.3kW, 6.6kW and more with respect to the OEM design. • To facilitate the V2G, the existing onboard charger inside the charger needs to be enhanced for bidirectional feature when 3.3kW charger is used. • The onboard charger needs to support remote communication for enabling charging and discharging back to grid. • In case of AC Type-2 charger, the charger also needs to be smart enough where it can be controlled remotely through necessary protocol. • Existing battery management system (BMS) of the EV to support the reverse flow and control the discharge whenever necessary to avoid deep discharge. • As the Battery is going to support grid, the design of the battery system and the inverter shall support the necessary Short circuit rating factor. **b. Fleet charger and Electric Bus charger:** • These are the locations where multiple vehicles are charged ranging from 150 kW to MW range. • Here Chargers used are in the range of 150kW to 300kW capacity supporting the charging of bus with battery capacity ranging from 200kWh to 300kWh. • Targeting those location chargers would yield more benefits for Peak load reduction and Peak shaving during charging **c. Peak shaving and Peak load support applications:** • When multiple vehicles are being charged at one locations, the chargers can be made	through proper integration of multiple system. **Role of EV OEM:** (i) Currently the prevailing onboard charger in the EV is a uni-directional charger ranging from 3.3 kW to 6.6 kW. Needs to be upgraded to Bidirectional feature. (ii) Sharing of BMS control to Utility and other service provider for V2G services. (iii) Vehicle compatibility with relevant ISO standards. **Role of EV Infrastructure OEM:** (i) Monitoring of chargers from a central control system. (ii) Access of charging data and sharing of data to utility for Load Forecasting and scheduling. (iii) Already there are around 10,000 plus charge points installed across India and it would reach 30,000 plus by next FY. Upgrading the charger to support V2G would be a costly affair. Needs support from EV charger OEM have a plug and play solution to support V2G. (iv) All EV OEM shall support by providing Mac-id or VIM number to track and monitor the EV participating for the V2G and for other purposes like pattern understanding etc. (v) Currently EV OEM offers a warranty support for Battery for 8 years or 1

	in master Slave arrangement thereby in case of any load reduction required to support grid, the controller can help in reducing the current and in turn reduce drawing of power. • Similarly, when power is required the same can be done by having an effective control over the BMS, State of charge and Charger control. • The chargers installed over the EV bus depot are mostly complying to IEC 61851, ISO-15118, DIN 70121. (v) Currently CHAdeMO is one of the standard supporting V2G whereas the CCS 2 standard is under development to support V2G and will be finalized by Next FY. (vi) Recommendations: Small Sub group to be formed within the committee to deliberate the details at micro level and form the necessary guidelines on Requirements in Chargers, Protocols to be adopted, Recommendation of EV OEM, Requirements from Utility stand point of view and Incentive model etc.	lakh km whichever is earlier. In case, the Battery is used for Peak load reduction purposes, it should not affect the warranty support from EV OEM. **Tariff:** Currently the batteries are being charged by EV tariff. The incentive mechanism to consumer in case of supporting to Grid shall be higher than the tariff being offered to EV for charging. For example in Roof top solar, the consumer is giving back to Grid at the tariff of his household whereas the power generation cost is lower than the Grid tariff. In similar way the compensation to be managed.
BSES	**(i) Phased wise implementation:** • Two wheeler and three wheeler commercial segments constitute a large percentage of EV and lay idle during night time. This segment utilizes battery swapping technology to fuel up the EV and hence in preliminary stage Battery Swapping stations shall be utilized during peak power period to support grid acting as a Distributed energy storage system. • Commercial Four wheeler electric fleet also utilize the fast public charging station for fuel up, DC fast chargers up gradation along with BMS can also be focused for V2G in India. **(ii) Challenges related to metering and grid safety:** In practice, guidelines related to integration of rooftop solar with grid, safety provisions and net metering regulations can be adopted in initial period to commence V2G in India.	**Cyber threat:** V2G in private space shall be concerns in cyber threat and breach of privacy if the vehicle is directly controlled from a remote system. Hence an additional charger / communication unit shall be the integrator between operator and EV use for control of energy exchange.
IIT Bombay	(i) Reactive power compensation in V2G mode may be relevant. e.g., reactive power support to the grid (as opposed to peak power shaving) offers the benefit of grid stabilization while having no harmful effect on battery life (as	**(i)** While 'Battery Swapping' centres could be potential targets for V2G, they could be limited to smaller 2W/ 3W batteries

	energy is not drawn from the battery since it can be supplied by an adequately-sized dc-link capacitor of the on-board charger). (ii) The first priority is to establish standards and interoperability. Generally, these are international standards and we in India should endeavour to participate in standard development. The CEA/ GoI could nominate some expert to the standard committee(s) who would also liaison keep this group informed on developments in IEC and IEEE. (iii) The second step would be to implement V2G on islands. This would involve drafting necessary standards that can facilitate use of V2G for emergency service along with existing diesel generators (DG), where ever DGs are used at present. (iv) The next step would be to go in for for grid integrated V2G. With metering infrastructure and regulations for revenue for V2G services. The services like frequency regulations etc., can follow later. (v) V2X (V2H;V2B etc.) technology may be explored for feasibility of V2G.	thus limiting the effectiveness of V2G.
IIT Delhi	(i) Role of Aggregator in V2G may not be neglected. (ii) Standardization of communication protocols is required for V2G. (iii) V2G may be possible through V2H/V2B.	
LOG9	**(i) Operating Energy Arbitrage Reserves:** Energy arbitrage involves buying electricity when it's cheaper and storing it, then selling it back to the grid when the electricity prices are higher. Electric Cab Aggregators / EV Fleet Operators can use their idle EV batteries during nighttime to perform energy arbitrage. They can charge the EVs during periods of low electricity demand and cheap electricity rates and discharge them during peak hours when electricity prices are high. **(ii)** V2G technology is evolving, and real-world implementation may face technical, regulatory, and implementation challenges that could affect revenue potential. It's essential to conduct a detailed feasibility study and collaborate with relevant stakeholders (like OEMs of Vehicle, Chargers and Distribution Utility) before implementing large-scale V2G operations. **(iii)** Implementing V2G indeed requires collaboration among multiple stakeholders and a	(i) V2G implementation challenges related to no control of a cab aggregator over the Battery Technology in the e-car, Battery Management System (BMS), non-availability/ enablement of bidirectional charger based feature in present ecosystem shall be needed, this will also require change in the programming logics & modifications in dock of the chargers and the car dock port, programmable logics for smart charging and discharging in synchronization with the

		comprehensive approach to address technical and grid-related complexities. Here's a more detailed analysis of the challenges and potential solutions: **a. Battery Technology and BMS:** **Challenge:** As a cab aggregator, Electric Cab Aggregators / EV Fleet Operators may not have direct control over the battery technology and BMS of the electric vehicles in their fleet. Different EV models may have varying battery chemistries and BMS capabilities, making it challenging to standardize V2G operations across the entire fleet. **Potential Solution**: Electric Cab Aggregators / EV Fleet Operators can collaborate closely with EV manufacturers to ensure that future EV models they add to their fleet are V2G-enabled. Engaging in discussions with manufacturers and conveying the benefits of V2G may encourage them to develop EVs with bidirectional power flow capabilities. **b. Bidirectional Charger Availability:** **Challenge:** The current charging infrastructure may not support bidirectional charging, making it necessary to upgrade the chargers and the car dock ports to enable V2G. **Potential Solution:** Electric Cab Aggregators/ EV Fleet Operators can work with charging infrastructure providers and grid operators to invest in bidirectional chargers at their charging stations. **c. Programmable Logics for Smart Charging and Discharging:** **Challenge:** Developing programmable logics that enable smart charging and discharging in sync with the grid infrastructure requires specialized expertise and software development. **Potential Solution:** Electric Cab Aggregators/ EV Fleet Operators can partner with energy management and software companies with experience in developing smart charging solutions. This partnership can help create an Energy Management System (EMS) tailored to their specific V2G needs, considering the grid conditions and pricing data from the energy exchange. **d. Understanding Local/Regional Grid Infrastructure:** **Challenge:** The grid conditions and peak/off-peak situations can vary at the local, regional,	grid infrastructure. (ii) Collaborating with the government or relevant authorities to offer incentives for charging infrastructure upgrades can accelerate the adoption of bidirectional chargers. (iii) A collaborative and joint approach involving EV manufacturers, charging infrastructure providers, grid operators, utilities, and energy management experts will be essential to overcome the implementation challenges of a large-scale V2G project for Electric Cab Aggregators / EV Fleet Operators. By leveraging the expertise of various stakeholders and investing in innovative technologies and solutions, Electric Cab Aggregators / EV Fleet Operators can pave the way for a successful and sustainable V2G ecosystem in India. (iv) Necessary permits and approvals from regulatory authorities to participate in energy services markets and provide grid support services.

and national levels, (i.e. on an energy exchange this might show peak pricing however in the state or locally the grid might be at off-peak) making it essential to understand the intricacies of the grid infrastructure for effective V2G operations.

Potential Solution: Electric Cab Aggregators / EV Fleet Operators can collaborate with local grid operators and utilities to gain insights into the regional grid's dynamics. This collaboration will help them schedule V2G activities intelligently, avoiding congestions and maximizing the grid's benefits.

e. **Net Smart Metering for Energy Accounting:**

Challenge: Accurate energy accounting is crucial for V2G operations, and implementing net smart metering for bidirectional power flow can be complex.

Potential Solution: Electric Cab Aggregators/ EV Fleet Operators can collaborate with utilities and regulators to establish net smart metering protocols specifically for V2G operations. This ensures transparent and accurate accounting of energy injected into or withdrawn from the grid.

f. **Partnership with Vertically Integrated Battery Technology Company:**

Challenge: Developing an Energy Management System and modeling energy exchange pricing require expertise and a deep understanding of battery technologies and grid operations.

Potential Solution: Electric Cab Aggregators / EV Fleet Operators can seek partnerships or consult with vertically integrated battery technology companies with expertise in energy modeling, energy exchange markets, and EMS development. These partnerships will bolster their capabilities in managing V2G operations efficiently.

(iv) The drivers operating the electric vehicles are essential stakeholders. They need to be trained in V2G technology, understand charging/discharging protocols, and collaborate with Electric Cab Aggregators / EV Fleet Operators to ensure the smooth operation of the EVs while optimizing their use for both ride-hailing and grid services.

(v) Although As per the Green Open Access Rules 2022 notified dated, 6th June, 2022states that the Green Open Access is allowed to any consumer and the limit of Open Access Transaction has been reduced from 1 MW to 100 kW for green energy, to enable small consumers also to purchase renewable power through open access. State needs to float the standard operation procedures (SoP's) for implementation. The regulation has to further amended for backward injection of power from multiple DER's / EV's in this case and cumulative addition for calculating total injected power at grid level, policy, regulations are in complete abeyance for such nuances.

(vi) Insurance Companies: Insurance companies provide coverage for the EV fleet and related operations, including potential liabilities related to V2G activities.

(vii) Financial Institutions and Investors: Banks and investors that have provided funding or invested in Electric Cab Aggregators / EV Fleet Operators have a financial interest in the company's success and its ability to generate revenue through innovative V2G services.

(viii) CCS 2 (Combined Charging System 2): Electric Cab Aggregators / EV Fleet Operators' electric vehicles use the CCS 2 standard connector for charging. The CCS 2 connector allows for both AC & DC charging and supports bidirectional power flow, enabling V2G capabilities. However, this has to be enabled by necessary modification in the circuitry.

(ix) Bharat DC 001 or GB/T Provisions: Electric Cab Aggregators / EV Fleet Operators to ensure that their EV models comply with the required Bharat Charger DC001, GB/T provisions for V2G. This involves coordinating with EV manufacturers to ensure the vehicles are equipped with the necessary components and communication protocols for bidirectional power flow.

(x) To assess the impact of V2G operations at scale, Electric Cab Aggregators / EV Fleet Operators to conduct simulations and pilot tests.

(xi) Recommendations:

a. Implement robust battery management strategies to ensure battery health and longevity during V2G operations.

b. Establish effective communication and collaboration with the grid operator to

	facilitate seamless grid integration. c. Comply with relevant regulatory requirements and work closely with authorities to create a conducive environment for V2G operations. d. Design incentive programs to motivate Electric Cab Aggregators / EV Fleet Operators' / other cab aggregator in coordination with Govt. to actively participate in V2G, thereby creating a successful distributed environment for V2G services.	

8. Recommendations for Implementation of V2G:

Electric mobility is an unprecedented opportunity to grow the share of VRE in the power system. EV charging can be coordinated with variable renewable energy generation to harness the potential benefits of managed charging, so as to promote smart-readiness of ecosystems through minimum communication and control requirements. The main strategy may be to maximize the amount of managed (or controlled/smart) charging, instead of unmanaged (or uncontrolled) charging. The cost-effective charging solutions that help to accelerate the shift to electric mobility may be facilitated. In order to unlock the technology and business models necessary to provide flexibility, the following are recommended:

- Standardization and interoperability among EV charging ecosystem
- Bidirectional charging system with standard and open source protocols
- Changes to be made in various Indian Standards pertaining to V2G
- The charging and discharging should be controllable via central monitoring system for providing synergies between mobility and the grid
- Design smart charging strategy to fit the power mix
- Complement grid charging with storage at charging points or battery swapping
- Advance integrated planning of power and transport sectors to avoid network congestion
- Build charging hubs in optimal locations to facilitate bi-directional flow between mobility and the grid
- Augmentation of EVs charging facility at workplaces as the vehicle is parked idle for around 5 to 6 hours.
- Facilitating advanced metering infrastructure establishments
- It is also important to note that although both V2H and V2G provide power flow from the EVs but they have differences in their underlying technology. The key difference between V2G and V2H is the type of inverter used by each system. As V2G runs parallel with generators, the inverters in the charging system may be 'Current Source' based which follows the voltage and frequency determined by the grid (grid following inverters) whereas V2H isolates the local network from the grid, so inverters may be 'Voltage Source' based that generates its own voltage and frequency command (grid forming inverters).
- OEMs may explore the capabilities of V2G-enabled EVs in executing the reactive power compensation, leaving the EV batteries charged and at the same time *does not expose them to additional discharging–charging cycles*.

- There should be a policy direction for sharing the controls between the various service providers for optimal utilization of charging infrastructure and to avoid any type of network congestion
- Amendment in “Guidelines and Standards for Charging Infrastructure for Electric Vehicles” in released by MoP where it is mentioned that EV charging operations to be considered as a service and not as sale of electricity.
- Enable revenue stacking for EVs in different markets through optimal tariff design
- Incentives for easy adoption by EV owners
- Globally, there exists technology for V2G however, the commercial implementation of the same is undergoing via case-to-case pilot studies. Therefore, it is suggested that pilot studies are also conducted in India for assessing the practical implications of the V2G technology.

Based on the above recommendations, the following may be incorporated in the CEA (Technical Standards for Connectivity to the Grid) Regulations.

(i) Suitable provisions for reactive power compensation for bi-directional charging infrastructure.
(ii) Standardization and interoperability among EV charging ecosystem as per the latest standards which shall be based on the open source protocol.
(iii) The charging and discharging shall be controllable via central monitoring system for providing synergies between mobility and the grid with the advanced metering infrastructure along with measures for congestion management in the grid.

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