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Vehicle-to-Grid (V2G) in India:

Potential and Scope for Driving EV Adoption

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Abstract

India has committed itself to increasing the number of Electric Vehicles (EVs) in its motor fleet with a slew of supply and demand side measures to boost their uptake. This White Paper considers the role Vehicle-to-Grid (V2G) technology can play in driving EV adoption in the country. V2G has emerged as a novel value stream for EV owners and represents a potential global opportunity worth USD 17.43 billion. With India heightening its efforts towards a shared, electric and connected future, this paper locates V2G as a potentially disruptive instrument in achieving India's adoption targets. The paper outlines a range of principles to guide future policy action in this domain and show the way for further research, collaboration and innovation.

Introduction

India has repeatedly demonstrated its commitment to play a seminal role in the ongoing paradigm shift in the mobility domain and lead the world towards a shared, connected and electric mobility future. The Government of India has aggressively pushed for the uptake and mainstreaming of electric vehicles (EVs) through a plethora of policy instruments, the most recent of which include the second phase of the Faster Adoption and Manufacturing of Electric Vehicles in India (FAME-II) scheme, production-linked incentive (PLI) scheme in advance chemistry cell (ACC) battery manufacturing, National Mission on Transformative Mobility and Battery Storage, and the Phased Manufacturing Programme (PMP) for setting up export-competitive integrated batteries and cell-manufacturing giga plants. These measures have shown encouraging results with a 20% increase in EV sales in 2019-20 over the previous year (PTI, 2020a). Though the COVID-19 pandemic has dampened sales, forecasts point towards a trajectory buttressed by buoyant growth. According to analysis by the India Energy Storage Alliance, the EV market in India is projected to grow at a CAGR of 44% from 2020 to 2027. Similarly, the annual battery demand is expected to grow by 32% over the same period (PTI, 2020b).

There are, however, certain lingering barriers that have prevented a warmer embrace of EVs in India. Anxieties surrounding performance and range, the total cost of ownership, inadequacy of charging infrastructure, and lack of consumer awareness about EV technology remain critically influential in driving EV adoption (Tarei et al., 2021). Barring purchase incentives through FAME subsidy, exemption of road tax and registration fee etc. to reduce the relative cost differential for EVs against internal combustion engine (ICE) vehicles, prevailing EV policies in the country have primarily focused on supply side incentives, with demand side incentives not being proportionate to their corresponding potential (KPMG, 2020).

This is especially true for electric four wheelers (e-4Ws). Electric two and three wheelers (e-2Ws and e-3Ws) may already be cost competitive with or without incentives for both individual use and commercial purposes. While incentives in some States, most notably in Delhi, have possibly helped tilt the total cost of ownership (TCO) scale favourably towards commercially registered e-4Ws, non-commercial e-4Ws continue to be less attractive from a cost perspective than their ICE counterparts (Patil & Ghate, 2020). TCO parity in itself may not guarantee mass adoption of EVs, but given the cost consciousness of most Indian buyers, the promise of even moderate savings will go a long way in enhancing the demand for EVs.

Focus of the study

There is a need, therefore, to diversify demand side incentives to boost uptake of EVs by identifying innovative incentive structures and instruments and provisioning for their implementation. This white paper looks at one such potential instrument in the form of Vehicle-to-grid (V2G) technology and considers the role it can play in accelerating EV adoption in the country. It identifies the potential monetary benefits that could accrue to EV owners through frequency response mechanisms, payments for selling excess energy back to the grid, and lowering electricity consumption charges by potentially leveraging differential energy tariffs etc. Another objective of this study is to lay the ground and argue for long-term investments and regulatory foresight to establish and entrench uniformly accessible bidirectional charging infrastructure at a macro, country-wide level. Additionally, it seeks to examine the interplay of EVs with the grid, charge point operators, DISCOMs etc. and proposes all-encompassing principles for concrete policy action on all related fronts.

What is V2G and how does it work?

V2G is a technology that allows for bidirectional energy flow, enabling energy stored in EV batteries to be pushed back to the electricity grid (Kempton et al., 2001). The essential idea is to modulate the charging and discharging of EV batteries in accordance with the users' needs and the demands of the grid.

When responding to the requirements of the grid, EVs could charge to their maximum level or change their rate of charging when the supply is high and subsequently, EV batteries could inject electricity back to the grid during peaks in consumption or in response to grid demands thereby serving as temporary energy storage units. V2G also offers scope for incorporating a greater share of intermittent renewable energy (RE) in the grid by allowing EVs to act as decentralised storage units during periods which are conducive for increased RE production. Figure 1 explains the operational process of V2G.

This technology has several different use cases depending on the electrical load that is furnished; the energy can flow from the vehicle battery to power the home- commonly called vehicle-to-home or V2H- or alternatively it could even be used to supply energy to a residential or office building, aptly called vehicle-to-building or V2B. Oftentimes, the term vehicle-to-everything (V2X) is used to denote the set of all possible use cases.

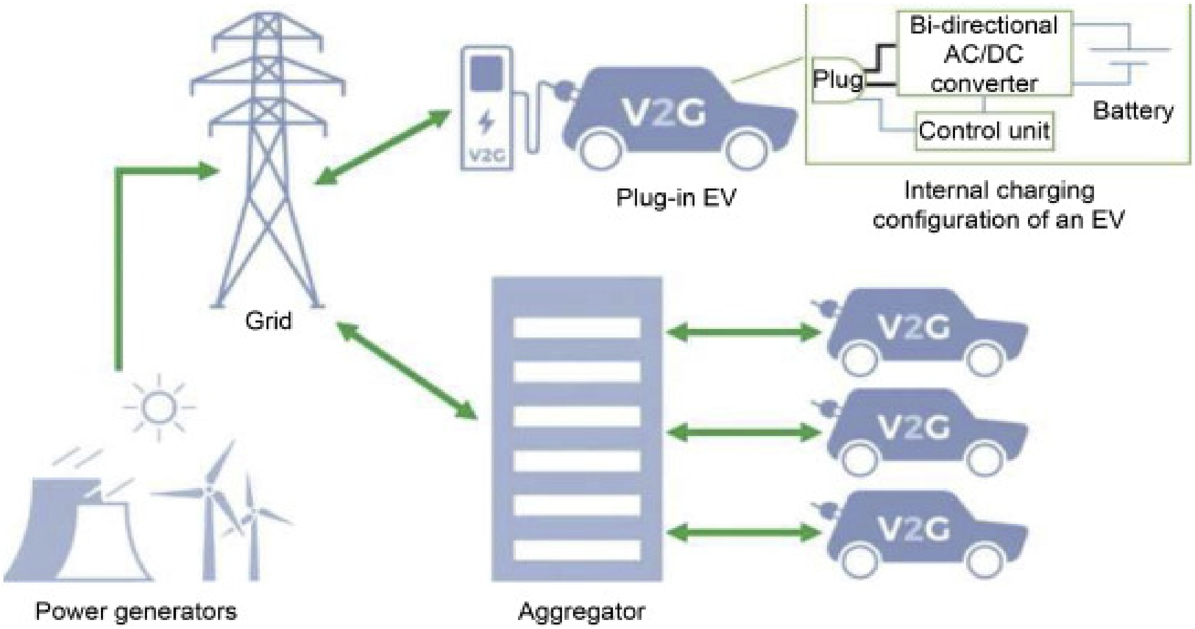

Figure 1 : V2G block diagram
Source: (Adnan Khan et al., 2019)

For charging an EV, alternating current (AC) from the grid is converted to direct current (DC), the kind that can be used by the vehicle. For orchestrating the reverse flow, the DC electricity used in the vehicle has to be converted back to AC. This can happen on-board the vehicle or off-board at the level of the charge point/ station depending on the kind of charger used (The Wallbox team, n.d.). The former leverages AC with the V2G charger placed in the EV itself. The vehicle can then be connected to the grid using a cable. Off-board V2G setups utilise DC current, and the hardware allowing for bidirectional flow is not in the vehicle but at the charge point/ station (On-board V2G versus Off-board V2G (AC versus DC), n.d.). The difference has been depicted in Figure 2.

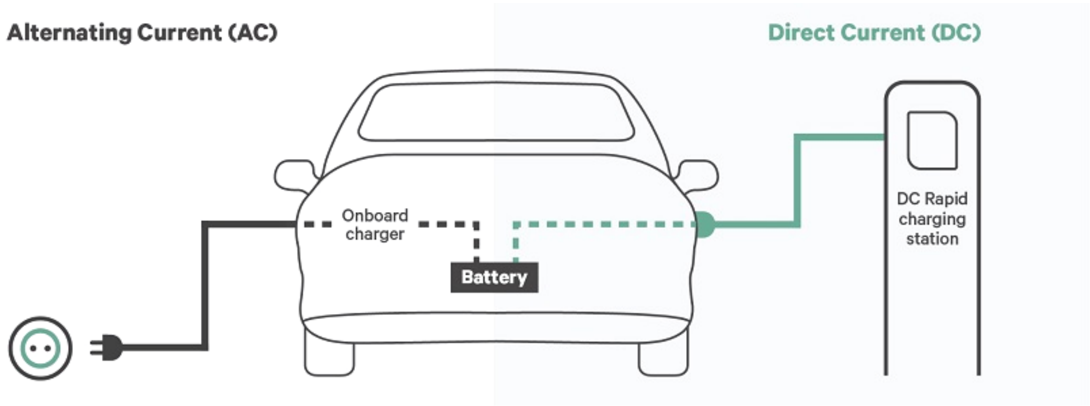

Figure 2: AC versus DC V2G setups

Source:Wallbox.com

Both mechanisms have their pros and cons.

Table 1: Pros and Cons of on-board and off-board setup		
On-board V2G (AC)	Pros	• Uses a simple adaptation of existing terminals. Less expensive for EV owners compared to V2G DC charger. • Authorities do not have to invest in expensive hardware at the charge point/ station.
	Cons	• Does not work with any standard AC charger; needs a specialised charger. • Costs for the internal electronics assembly are expensive on account of strict automotive requirements and limited space. • Noise can be discomforting. • Charging efficiency can typically be 10% less than an off-board charger for a single cycle.
Off-board V2G (DC)	Pros	• Faster and more efficient charging • Minimal intervention required in the car • Lower noise levels • Greater hardware maturity compared to bidirectional AC chargers.
	Cons	• The DC cable and plug are highly expensive.

Source: (On-Board V2G versus Off-Board V2G (AC versus DC), n.d.)

There has been significant interest in devising AC solutions, with Renault taking the lead and testing the first large scale AC charging V2G pilot with 15 Zoe EVs across several European countries beginning with the Netherlands and Portugal (Kane, 2019b). A vast majority of V2G operations, however, are off-board DC setups using the CHAdeMO protocol. The other common rapid charging DC connecting standard- CCS- currently does not offer V2G capabilities, though it plans to by 2025 (Kane, 2019a). The combined charging station and EV constitute a distributed energy resource (DER). The different compositions making up the DER have different communication requirements (Das & Deb, 2020).

Moreover, there is a need for a control system to manage the discharging process to make sure that the exported energy is used safely and effectively. These control systems also have a standard communication protocol to undertake back-end communications between the charging stations and charging station management systems.The most common standard protocol used in such systems is the Open Charge Point Protocol 2.0 (OCPP 2.0), which allows for the mix-and-match of different software and hardware (Das & Deb, 2020).

Potential and Scope for V2G in India

Currently, V2G functions predominantly under tight experimental conditions. Having said that, there are substantial gains to be achieved provided necessary and timely investments are made. Analysis by Precedence Research (2020) shows that the global V2G market will garner revenue worth USD 17.43 billion and grow at a CAGR of 48% during 2020-27. This is a growth opportunity India must not miss. As a long gestation infrastructural initiative, there is an urgent need to discuss issues regarding V2G and the advantages it offers since envisioning, designing and implementing the technology will take time, investment, and consistent political commitment.

Imperatives for India

V2G presents a slew of opportunities from driving EV adoption by decreasing the TCO for EV owners to integrating renewable energy, balancing the grid as well as providing emergency power backup services . The imperatives are, therefore, diverse and varied. A careful examination of each is warranted.

1. Promote uptake of EVs by lowering TCO

India has experimented with a range of measures to make EVs attractive to its potential customers. Demand side measures under FAME- II, for instance, provide an incentive in the form of an upfront reduced purchase price. The incentive, however, is not applicable on Electric 4W bought for private use (Baggonkar, 2019).

As mentioned earlier, even minor alterations to the TCO can have ripple effects in the EV market. Initial studies from mature markets show that EV owners could potentially make USD 300-500 per year through V2G (Malmgren, 2016). This subsection looks at three prominent revenue generating value streams associated with V2G that can be leveraged to reduce TCO and make EV purchases more economically attractive in India.

(a) Frequency response and reserve

The supply and demand of electricity needs to be in balance for the grid to function optimally. Aggregated into portfolios, EVs can help fill a shortfall by discharging and exporting their power to the grid. Similarly, if there is an excess of power in the system, the EVs can start charging to absorb some of that power. This can occur over different timescales. ‘Frequency response’ mitigates deviations in system frequency[1] within 1-30 secs, subject to market requirements. ‘Reserve’ requires power to be exported within minutes to hours by increasing power generation or reducing demand (National Grid Electricity System Operator (ESO), 2019). Frequency response can be both static as well as dynamic. Static frequency response is a predefined fixed response service that is activated when the frequency

[1] The power grid is tuned to operate at a specific frequency. Britain and India maintain it at 50Hz. The United States has it at 60Hz (Bhalerao, 2018).

drops below a specific threshold. Dynamic frequency response, on the other hand, seeks to respond to shorter duration, second by second deviations (Open Energi, 2015). The latter has been shown to be both more suitable to V2G and more profitable than the former (Payne, 2019). Frequency regulation can, therefore, be a lucrative endeavour for V2G enabled EVs.

Massive scope has been indicated in the Nordic market, with the Parker project in Denmark clocking in average annual revenue per vehicle at 1,860 Euros (Cenex, 2020). Table 2 presents examples of revenue estimates associated with frequency regulation from studies that have been undertaken over the years. These figures are indicative and inferences, if any, should be drawn only after a careful and cautious consideration.

Table 2 : Revenue estimates for potential earnings from frequency regulation services

Study, Location [original currency, year]	Application	Net Revenue Estimate (2016 USD/ vehicle-year)	Major Assumptions and Variables
Kempton and Tomić (2005), United States [USD, 2003]	Calculations based on a single Toyota RAV4 EV	USD 2,250 (10-kW charge point) to USD 3,320 (15-kW charge point)	Vehicle is plugged in and available 18 hours/day. Study assumes USD 650 (2016 USD 850) for residential wiring upgrades needed for 10-kW charge point, USD 1,500 (2016 USD 1,950) for 15-kW charge point.
Agarwal et al. (2014), Singapore [SGD, 2012]	Pool of 10,000 private light duty vehicles, 10-year vehicle lifecycle analysis	USD 1,508	Vehicles plugged in and available 22 hours/day. Market price of SGD 91.53 (2016 USD 76.89) per MWh for regulation services.
Mullan et al. (2012), Australia [AUD, 2009]	Pool of 60,000 private light duty vehicles	Revenue of USD143 (deemed not profitable if costs are subtracted)	Based on data and costs from the South West Interconnected System (SWIS) in Western Australia, assumes current budget of ~AUD 9.8 million (~2016 USD 8.7 million) for regulation service.
Ercan et al. (2016), United States [USD, 2014]	Fleet transit or school buses	USD17,384 (school bus), USD6,170 (transit bus)	Life-cycle cost comparison with diesel versions in the California Independent System Operator region. Values shown are per-year revenue estimates over an assumed 12-year life.

Source: Data sourced from Steward (2017) writing for the National Renewable Energy Laboratory (NREL). Steward has converted currencies to units of USD 2016 to provide consistency between studies.

Simulations for a local frequency response system in the case of Britain have shown financial promise (MENG et al., 2015). However, a few things must be kept in mind. All the mentioned projections for financial gains are contingent on a number of assumptions: the availability of sufficient EVs to be readily plugged into the grid; the willingness of EV owners to schedule their trips keeping the need of the utilities in mind and operate their vehicles at a State of Charge (SoC) that may be at times be less than optimal; and the presence of communication mechanisms for efficient two-way linkages between the EV and the charging station(s) and as a corollary to that- between the charging station(s) and the grid.

Mature pilots position frequency response at a risk of falling prices due to a possible saturation of the market as well as competition from other fast response assets such as fixed battery systems (Cenex, 2020). Having said that, frequency response remains one of the main revenue generating opportunities associated with V2G.

(b) Arbitrage

Provided there are variable tariffs in place- either as Time-of-Day (ToD) or some other form of Time-of-Use (ToU) tariff structure or alternatively in the form of real-time electricity pricing- individual EV owners and fleet aggregators can take advantage of energy price differentials. They may buy electricity when the electricity prices are low and store that energy in the EV battery. Subsequently, they may sell this electricity on the power market when prices become high thereby leveraging the tariff differential to earn money (Das & Deb, 2020). Since variable tariffs are a prerequisite for revenue generation through arbitrage, the energy supplier becomes a key stakeholder in this process.

While variable tariffs are becoming increasingly common, grid services require an aggregator to "combine assets in order to bid into markets, adding complexity and a third party with which to share revenue" (Cenex, 2020). The revenue or saving realised is further dependent on the magnitude of the charging and discharging efficiency and conversion losses as well as the possible costs incurred with respect to battery degradation or replacement on account of repeated cycling. There are, however, conflicting views on the impact of repeated cycling on the health of the battery. These concerns have been discussed in brief in a later section. Hopefully, a clearer picture should emerge with the passage of time and the implementation of further pilot projects.

In the meantime, arbitrage should continue to be an attractive revenue generation option for owners of V2G enabled EVs. A summary of some selective studies detailing the potential monetary gains through arbitrage can be found in Table 3 below. While the findings have been presented together for the sake of brevity and readability in order to point towards the monetary potential of arbitrage, it must be noted that the findings may not be directly comparable owing to the differences in study design, considered tariff rates and structures, durations of V2G charging etc.

Table 3 : Estimates for earnings through arbitrage

Study, Location [year of study, type of study]	Driving pattern and V2G availability	EV specific characteristics	Battery degradation	Pricing scheme	Profit
Almehizia and Snodgrass (2018), USA [2011, simulation]	V2G availability: 8AM to 5 PM. Driving distance per day: 32 miles	Tesla Model 70D 70kWh battery. Round Trip Efficiency (RTE)[2]: 80%	10.42 cents/kWh	Fixed night charging cost 5.95 cents/kWh. Dynamic pricing during day from ERCOT RTM[3]	USD 338.56 per EV per year
Peterson et al.(2010), USA [2008,	V2G availability: 5PM to 7AM.	16kWh. Lithium Iron Phosphate (LPF) battery. RTE: 85%	4.2 cents/kWh	Considers dynamic pricing from PJM, NYISO, and	Without battery degradation: USD 140 - USD250 per

[2] Round-trip efficiency is the fraction of electricity put into storage that can be later retrieved. The higher the round-trip efficiency, the less energy is lost in the storage process.
[3] Electric Reliability Council of Texas Real-Time Market

simulation]				ISO-NE for 2008[4]	EV per year With battery degradation: USD10-USD120 per EV per year
Kiaee et al. (2015), UK [2013, simulation]	V2G availability: 9 Hours. Driving duration per day:10 - 90 minutes	60 kWh. RTE: 100%	No	Electricity price signal on 12 Nov 2013 is considered for all simulation days.	13.6% (GBP 1799.77/5000EVs/5 days) saving in charging cost with V2G when compared to without V2G case.
Uddin et al. (2017), UK [2016, experimental]	V2G availability: 9 Hours	30 kWh. Nickel Cobalt Aluminium (NCA) battery	Based on actual degradation from the experiment.	UK energy pricing	USD 555 per EV per year saving from improvement in battery life.
Malya (2020), Germany [2019, simulation]	V2G availability: 9 Hours. Driving distance: 32.63 km	24 kWh Lithium Manganese Oxide (LMO) battery. RTE:85%	Xu model[5]	German day ahead pricing signal for 2019	Without battery degradation: 43.158 Euros /Year/EV. With battery degradation: 123.28 Euros /Year/EV[6]

Source: Data sourced from Malya (2020)

(c) Time shifting

While both frequency response and arbitrage often require substantive regulatory and operational or logistical changes to implement, time shifting is a much more straightforward revenue stream to put into action. Given differential tariffs are in place, savings from time shifting accrue when EV owners shift the time at which they consume electricity thereby reducing charges and/or increasing self consumption (Everoze & EVConsult, 2018). EV owners could, for instance, charge the EV at low prices or during periods of high onsite solar generation and then discharge the EV, into their homes or at their business location, when the prices are high. The overall cost of energy consumption can go down substantially depending on individual consumption patterns and the price variability between tariffs.

The relationship between intermittent renewable energy generation and V2G has been probed in greater detail in the next subsection.

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[4] Pennsylvania-New Jersey-Maryland Interconnection; New York Independent System Operator; Independent System Operator New England

[5] XU model describes a technique for modelling battery degradation for LMO batteries.

[6] The anomaly is due to the simulation algorithm adopted keeping the LMO battery in mind. The battery is highly sensitive to high temperature. Performing V2G helps maintain a low SOC which in turn causes less battery degradation than the case in which V2G is not undertaken.

2. Grid decarbonisation: Effective energy storage option for intermittent renewable energy (RE)

India is targeting a share of 40 per cent for its renewables in its power system by 2030, with a total installed capacity of 450 GW (Joshi & Jaiswal, 2019). With growing RE penetration, DISCOMs are facing a host of challenges such as "the high balancing costs of intermittent RE and an increased need for greater system flexibility" (CEEW Centre for Energy Finance, 2021). To address these challenges, there has been a recent shift towards innovative RE procurement models in India such as hybrid and 'assured peak power supply' models as well as the deployment of grid-scale battery storage in many parts of the world (CEEW Centre for Energy Finance, 2021). With a large forecasted fleet of EVs, expected to reach 102 million units by FY30 according to research by Singh et al. (2020), V2G techniques can help EV batteries store excess output generated by energy sources like wind and solar and release them at times of peak demand thereby helping balance supply with avenues and timings of increased demand.

For instance, EV users could be incentivised to charge their vehicles during the day when solar energy is plentiful. This may be made possible through the use of EV chargers at the workplace that take advantage of vehicles that remain parked and idle for long periods. In the evening, when electricity demand peaks and solar energy is not available, users can plug in their EVs to a V2G charger located at or near their homes. These V2G chargers would feed into the grid, thereby helping meet the peak demand.

Two case studies from India- one concerning itself with solar and the other with hydropower- have been presented below to serve as examples as to how this approach can be emulated at scale as India goes about increasing its share of intermittent renewable energy in its grid.

1) Case I: Simulation carried out by TERI in Delhi

Objective of the study: The study simulated a V2G model for a typical summer day in Delhi, in order to assess its utility in promoting peak shaving/ shifting through time-of-day/ differential tariff mechanism, demand response (DR) and demand side management (DSM), integration of solar rooftop, and potential for emergency back-up applications.

Findings: EV can be used to supply power to the grid (V2G) from its storage during peak hours and be charged back from the grid during off-peak hours or when output from solar radiation is maximum (Datta, 2018).

Lessons learnt: i) Aggregated models can help charging stations and EVs save on high storage costs. ii) Time of Day (ToD) tariff should help manage peak hour demand and vehicle owners could be given financial incentive to participate in giving power back to the grid . iii) V2G could also help India achieve other goals such as higher grid integration of renewables, enhanced fuel security brought out by larger penetration of EVs, and a transition to a low-carbon pathway for growth (Datta, 2018).

2) Case II: Simulation carried out by members of the EEE Department at Amrita University in conjunction with an Assistant Engineer at the Kerala State Electricity Board to consider the value proposition of V2H in hydropower-dependent Kerala.

Objective of the study: The study attempts to provide strategies to increase the cost advantage of EVs by reducing its payback period by exploring the possibility of vehicle-to-home (V2H).

Findings: The simulation confirms that the envisaged V2H setup would be capable of feeding peak power to 45-50 urban homes of Kerala for a duration of 1-1.5 hours. Moreover, it argues that additional savings can be achieved by downsizing the required transformer capacity from 250kVA to 100kVA. Given Kerala is highly dependent on unpredictable hydropower supply, the authors argue that the need for scheduled power cuts can be minimised if V2H is leveraged for load levelling (Kumar et al., 2015).

Lessons learnt: i) V2H can enable capacity enhancement during peak load hours in the Indian scenario by utilising the stored energy available in the EV. ii) V2H can go a long way in addressing two major technological problems, namely, the relative cost disadvantage of EVs and peak levelling of Indian power grid. iii) While the hypothesis has been made for a specific state, the study claims that similar benefits can be expected in other Indian States as well (Kumar et al., 2015).

3. Additional Benefits for India

In addition to the imperatives mentioned above, there are certain other advantages that India could expect with implementation of V2G, most notably with respect to its potential role in stabilising the grid. Such services that cater to the Distribution System Operators (DSOs) are called DSO services.

Peak shaving

Peak shaving refers to levelling out peaks in electricity demand by proactive management of said demand and the elimination of short term demand spikes. While peak demand occurs rarely, utilities are implored to account for them through investments in generators or networks to supply such quantum as may be necessary to sustain the peak demand. As such these investments and assets mostly remain underutilised (Jones et al., 2021). V2G enabled EVs can help manage the overall demand load by exporting energy at times of peak demand and then charging up during off peak periods. Considering this process does not require any additional hardware investments, V2G can allow utilities to deal with peak demand in a cost-effective manner. Additionally, V2G can help avoid local network congestion wherein networks may not have adequate capacity to transport the required electricity to the consumer (Jones et al., 2021). This is called constraint management. V2G can improve network asset utilisation and defer the investment in transmission and distribution assets such as power lines and transformers which, in turn, can reduce network charges for all connected customers.

A study conducted at University of California, Los Angeles with 30 EVs used a smart algorithm and bi-directional charger to flatten the original base load curve by shaving the peak by approximately 30% (Gadh, 2018). Similarly, a demonstration at Colorado's Fort Carson Military base using two electric trucks, achieved 43 kW of peak shaving worth approximately USD 860 (Millner et al., 2015, as cited in Steward, 2017). Peak shaving can also, therefore, much like the services discussed earlier, be financially profitable for EV owners. A cost-benefit analysis for V2G in Shanghai, in fact, showed that the larger the fleet of vehicles participating in V2G, the more the peak shaving load is, and the greater the users' income will be (Li et al., 2020).

Reactive power support

Voltage control has become increasingly challenging with more and more distributed energy resources (DERs) exporting power into networks that are already operating near the maximum limits of their voltage ranges. Generally, voltages are regulated by controlling reactive power. Reactive power is "the power that flows back from a destination toward the grid in an alternating current scenario" (*Reactive Power*, 2021). Decreasing reactive power causes voltage to fall while increasing it makes voltage rise. V2G equipped EVs with appropriate controls can offer voltage support and power factor correction by controlling the reactive power without any material effect on the battery. "Reactive power can be injected into the grid from a V2G EV charger by controlling the AC-DC converter and the DC-link capacitor without affecting the current drawn from the battery. This also means that, in case of DC chargers where the converter is installed in the charger instead of in the vehicle, the vehicle may not be required to be plugged-in for the charger to provide reactive power support. This makes the installation of V2G DC chargers extremely useful for reactive power control" (Jones et al., 2021). A number of studies (Rogers et al.,2010; Liu et al. 2018) have demonstrated the efficacy of EVs in helping stabilise the grid through voltage and frequency regulation.

Network security and demand forecasting

As discussed earlier, V2G can improve the grid's capability to quickly respond to sudden disturbances thereby enhancing the strength of the network to recover from minor shocks and demand fluctuations. Moreover, anonymised data collected from charging points can help grid engineers predict future demand patterns and improve grid performance through network planning and by making necessary operational adjustments (Jones et al., 2021).

EV batteries as emergency inverter backups

In the case of a power outage or scheduled load shedding- the latter of which continues to be a common phenomenon in emerging economies like India when faced with increased demand burdens- bidirectional charging setups can leverage existing charge in EV batteries to make them act as an emergency backup unit for temporarily powering the home or business premises (Ahmad & Sivasubramani, 2016). E4W and larger vehicle batteries are large enough to provide emergency power for lighting, common home appliances etc. for several days through V2H applications. In fact, EV batteries can augment or even replace existing back-up or UPS systems. Depending on local requirements and suitable applicability, this could result in cost savings and potentially lower the carbon footprint if reliance on diesel generators or system sizes can be brought down (Cenex, 2020). The concept holds immense promise in disaster-prone regions. Japan has used V2H to combat electricity loss during tsunamis and earthquakes (Gerdes, 2019). Given the recent spate of cyclonic activity on Indian shores with cyclones Tauktae and Yaas causing widespread destruction, the potential for this usage must be probed in India's specific context.

Personal Net Zero/ Self Sufficiency

EV owners with access to on-site renewable energy technologies such as small-scale wind and solar PV (photovoltaic systems) can optimise their self-consumption of energy. This will, of course, depend on whether the given site's on-site generation profile exceeds its consumption profile at any point (Cenex, 2020). If it does, an absence of technical risks, strong consumer interest, and the increasing importance of enhancing one's environmental reputation for both members of the public and businesses at large make this a very strong value proposition for diverse consumer groups in India. Further, "V2G can also promote investment in increased generation capacity and low-carbon consumption technologies such as heat pumps" (Cenex, 2020).

Challenges for India

Existing EV scenario and segment-wise penetration profile

India's current EV penetration levels are incredibly low with EVs accounting for less than 1% of the overall automobile market: there are less than 1 million registered EVs out of 230 million registered motor vehicles in the country (Jain, 2020). Most starkly, only 0.07% of the cars in India are electric (Kaul, 2020). The overwhelming majority of EVs in India are e-2Ws and e-3Ws, both of which have limited practical utility for V2G given their small battery sizes. While there have been studies that have looked at the use of e-2Ws for V2G, such as by Hsu et al. (2018), monetary gains for individual e-2W owners are likely to be miniscule even if aggregation can be achieved. Even in the case of cars, none of the EV models available in India at present allow for bidirectional charging. Moreover, India's EVs remain unaggregated and geographically spread out making it hard to strategically locate bidirectional charging points, and raises legitimate reliability concerns for utilities seeking to scale V2G for grid services such as peak shaving and voltage control. Thankfully, going by research by Singh et al. (2020), e-4W are forecasted to see a sizable increase in India[7] and coupled with a coterminous reduction in V2G hardware costs, India's EV profile should become more in sync with the demands of V2G implementation at scale.

Absence of regulatory provisions and logistics data for aggregation of DERs

For EVs to participate in the provisioning of energy to the grid, there must be a regulatory regime to allow for seamless integration and aggregation of distributed energy resources (DERs), including EVs. The existing electricity transmission and distribution setup in India is highly centralised with a lack of regulatory impetus for third party aggregators to participate in resource aggregation. EV aggregation is necessary for an adequate response to wholesale market signals (Das & Deb, 2020). While regulations on certain minimum thresholds for participation as a grid resource are necessary, the current thresholds for participation are unfairly high for smaller players looking to play a part in the local power market. There is an unhealthy obsession with power supply measurable in kW even though similar quantities of energy can be acquired through a larger number of aggregated DERs. Additionally, there is a need for reliable data about different customer archetypes and historical use case scenarios for aggregators to properly assess their ability to serve the grid at given points in time and stack value for their customers of different kinds (Jones et al., 2021). Such granular data regarding charge timings, trip route etc. is currently lacking in India's case for potential aggregators to leverage.

Lack of robust communication networks and protocols for linkages with the grid

V2G is ideally suited for a fully operationalised smart grid. Even in the absence of a strong smart grid infrastructure, V2G may still be feasible provided there are robust communication networks and protocols for relay of information across various nodes of the grid and between the wholesale market and the aggregators. V2G requires near real-time communication between the utility and the charging station and also between the charging station and the individual EV. On the other hand, V2G also involves "two types of communication functions: receiving wholesale market signals for the resource and sending meter performance data to the wholesale market" (Das & Deb, 2020). A communication standard is essential to sending and receiving messages between the aggregator and the wholesale market. Standards will also be required for downstream communication to ensure that each participating entity of the V2G programme is equipped to respond to the message (Das & Deb, 2020). Communication is also needed to make sure that the potential difference during charging does not lead to reverse flow of energy. India is currently not well positioned to have a common standards umbrella. It could consider OpenADR, a commonly used and highly secure two-way information exchange model and Smart Grid standard. ISGF has partnered with OpenADR alliance to seek out case use scenarios and opportunities in India (*OpenADR Alliance, ISGF Partner on India's Smart Grid*, n.d.). Widespread applicability, however, is still several years away.

Absence of an ancillary service market

India lacks an ancillary service market in the power sector to allow for frequency response and voltage control to be actualised as veritable value streams. Only slow tertiary reserves are currently used. Yet another obstacle is that the DISCOMs primarily opt for above-mentioned services to "bridge supply gaps during peak hours, which defeats the very purpose of ancillary services. Until an efficient ancillary service market emerges in India, leveraging V2G benefits will remain a distant possibility, which, in turn, hurts the business viability of V2G" (Das & Deb, 2020). The Central Electricity Regulatory Commission (CERC) has recently released the new draft Ancillary Services Regulations, 2021. The draft

[7] Forecasted number of e-4Ws by 2030: 5 million units

regulations allow for the participation of energy storage and demand response resources in the provision of ancillary services (Ranjan, 2021). While this is definitely a progressive step, a lot more still needs to be done. Additionally, policymakers must desist from centralisation tendencies. EVs can offer better support through local market mechanisms than through centralised structures for ancillary services delivery.

Prevailing tariff structures

Price signals are necessary for any meaningful bidirectional flow of energy. Time of Use (ToU) tariffs are one of the most commonly used methods to signal savings or earning opportunities for V2G equipped EV owners. In India's case, respective State Electricity Regulatory Commissions (SERC) are responsible for determining tariffs for different consumer categories with the National Tariff Policy providing overarching guidance for the same. The category under which EV charging falls, differs from State to State. While some like Goa have added a separate category called Public EV Charging Stations, others like Andhra Pradesh or Punjab have specified EV tariffs under the existing categories. Three States- Uttar Pradesh, Kerala and Maharashtra- have notified Time of Day (ToD) rates specifically for EV charging (Das & Deb, 2020). EV specific ToU tariffs are, therefore, a starting premise for a V2G ecosystem. However, ToU rates are no panacea and there are concerns that they may create new peaks as the EV penetration in a given region increases (Das & Deb, 2020). Real-time dynamic pricing as an extension of ToU rates should be explored to prevent secondary peaks and accurately reflect market and grid conditions. Upper thresholds may be set to prevent exorbitant charges for customers. The efficacy of dynamic rates is yet to be established beyond doubt and there are fears that the implementation burden in terms of investment required might be too large for a country like India. Additionally, the added complexity may hinder wider customer participation by obfuscating visible monetary gains (Das & Deb, 2020).

Complex Value chains

V2G value chains have myriad actors including, but not limited to, the vehicle user, the vehicle owner, an aggregator and an energy supplier. For V2G to be a viable business model, all these stakeholders should be able to extract some financial value from the endeavour which limits the profitability for each player (Cenex, 2020). These stakeholders must share whatever revenue is generated. Therefore, unless the gains are substantive each actor is less likely to continue participating in the process thereby potentially imperiling the whole value chain.

Nudging customers towards behavioral and attitudinal changes

A big challenge for V2G implementation at scale is to convince EV users to promptly respond to price or demand response (DR) signals from utilities and change their trip routes and schedules accordingly. Even if the EV may not be in a position to readily respond to the said signals, the charge point operator must at least have reliable forecasts about the timings at which EVs may be available to participate in bidirectional flow back to the grid for them to assess the capacity of power that they can provide to the power market. This can be especially detrimental to the business viability considerations given that many of the benefits associated with V2G in any case do not lend themselves to neat and accessible valuations. Similarly, it will be hard to convince EV owners to let their vehicles operate at a state of charge (SOC) that is less than the maximum possible amount of charge for the battery. These issues are in no way unique to India. The pilot carried out at the University of California, San Diego (UCSD) (discussed in the next section) also came to the conclusion that predicting available capacity in advance can be cumbersome and challenging especially with a highly limited number of EVs and varying personal schedules of drivers (Everoze & EVConsult, 2018). Both the challenges discussed above may be addressed, to some extent, through aggregated consumption and supply mechanisms such as coordinated EV fleets or battery swapping stations or even electric bus fleets that may operate at fixed timings. For tapping the true earning potential that V2G can offer to individual EV owners, however, a host of measures including proliferation of charging points, design of strong time-sensitive incentive structures as well as changes in tariff structure and rates will be necessary. These have been discussed in a later section that deals with principles to guide future policy in this domain.

Concerns about the suitability and the performance of batteries indulging in V2G

As mentioned earlier, batteries of e-2W and e-3W are not of optimal size to support V2G, the vehicle classes which form the majority chunk of EVs in India. The added problem in India's case is that the EVs on sale here mostly have batteries with discharge rates of 0.3C. The C rate denotes the rate at which a battery is discharged relative to its maximum capacity. A 1C rate, therefore, means that the discharge current will discharge the entire battery in 1 hour (MIT Electric Vehicle Team, 2008). For V2G, batteries with discharge rates less than 1C are not particularly suitable. High discharge rates, however, have their own set of problems. In a country like India with high ambient temperatures, high rates of discharge could result in excess heat and manifest as a serious safety hazard. Thankfully, battery management systems (BMS) can take care of these issues (Das & Deb, 2020). There are also challenges relating to battery degradation management with a paucity of sensing techniques and algorithms to assess and guide usage towards the expansion of battery life. Finally, there are anxieties regarding the impact of V2G on battery performance and its longevity. While some studies have suggested that repeated cycling degrades the battery, yet another group of scholars, led by Dr. Kotub Uddin from the University of Warwick, has demonstrated the opposite. Their research has shown that provided 'optimised' or 'smart' V2G systems are employed that are designed to work more responsively and efficiently, not only is the adverse impact of V2G limited, battery life could even be extended beyond the case in which there is no V2G (Uddin et al., 2018). Pilots from Denmark (ACES project) and California (INVENT project) found the battery degradation on account of V2G to be minimal (Marinelli et al., 2020; Everoze & EVConsult, 2018). Having said that, it could be argued that the effects over the long term could be drastically different. More pilots and simulations should give us a better understanding of the issue.

Additional infrastructural investments and upskilling requirements

Notwithstanding the expected expenditure on bidirectional charging points and grid upgrades, there are a host of supplementary infrastructural investments that need to be made for successful V2G implementation in India. These include the need for two way smart metering, the necessary infrastructure to discharge EV batteries with different States of Charge (SoCs) at the same charging point, investment in CHAdeMO chargers etc. The grid and charging station operators must undertake additional costs of monitoring and controlling the vehicle-grid interactions, paying owners, and administering the system. The charging station should also have "appropriate Loss of Mains (LoM) protection equipment to ensure the vehicle does not feed power into the grid during a fault or when maintenance work is underway" (Das & Deb, 2020). Additionally, implementing V2G will compel grid engineers and maintenance workers to upgrade their skills in order to put the required changes into action. For instance, bidirectional battery chargers have a complex controller and a high-tension cable, with the latter requiring safety precautions to be taken. Likewise, the performance of CHAdeMO chargers is dependent on operating conditions, highlighting the importance of proper calibration and a thorough knowledge of the employed hardware on part of the operator when providing services via V2G (Das & Deb, 2020).

Review of global V2G pilots

Figure 3: An overview of V2G pilots in the world. The number denotes the number of pilot(s) in the given region.
Source: Data taken from V2G-hub.com

The section looks at a few successful V2G pilots that are being, or have been, implemented in various parts of the world (Table 4). The purpose is to derive lessons that can be learnt from these studies and assess whether, and to what extent, they provide a basis for emulation in India.

Table 4 : Review of global V2G pilots

Name of the Pilot, location, period of operation Project description	Operational details	Services offered	Results and lessons learnt
Parker project, Denmark, 2016-18 Project sought to test the ability of electric vehicles to provide grid services using real world fleets.It identified and addressed barriers to commercialisation. And compared the capability of different cars. It was the world's first fully commercial vehicle-to-grid hub:	Vehicles used: Nissan LEAF (30kWh), Nissan E-NV200 (24 kWh) & Mitsubishi Outlander (12kWh) Charging location: Work (utility) Charge Point: 50 units ENEL 10kW DC charger Customer offer: Monthly fee which includes charger	Frequency management, constraint management, intra day/day ahead trading for third party intermediaries.	i) It is possible to commercialise this technology through the provision of a Frequency Containment Reserve (FCR). ii) Key regulatory barriers identified include- 1) poorly defined grid connection pre-qualification process given likelihood of different cars & chargers and need to assess performance at aggregated level; 2) high cost of settlement meters; 3) high energy tariffs and taxes, including double counting. iii) Technical barriers included: 1) long duration frequency bias – service required often exceeded kWh capacity requiring lower kW bids; 2) two way energy loss - discharging at power levels lower than the rating of the charging equipment resulting in low efficiency and high losses.

City-Zen project, Amsterdam, 2014-19 Small-scale commercial project with pioneering focus on DSO services. Adopted a holistic approach with multiple power sector use cases.	Vehicles used: 2 Mitsubishi Outlander, 2 Nissan E- NV200, 1 Nissan LEAF Charging location: Work and public Charge Point: 4 DC V2G chargers, 10 kW, MagnumCap Customer offer: Customers paid flat rate of 10 Euro cents/ hour of plug-in time (subsidised by public funding)	Constraint management, power quality regulation, third person intermediary energy trading	i) Favourable response time observed, only marginally slower than stationary batteries. ii) In terms of market readiness, DSOs engaged proactively with V2G, and this is expected to create new revenue opportunities in the future. Barriers include legacy solar subsidy regime, and unclear grid acceptance requirements. iii) A key finding was that it is crucial to ensure that grid stability does not interfere with the charger. The City-zen team recommended that grid acceptance standards be amended to make it mandatory for 'slow starters' to be incorporated into all V2G chargers. Slow starters limit the inrush of voltage, making the power quality more stable, and the cost of incorporating them is supposedly low. iii) Biggest challenge was with availability of assets for usage (i.e. plug-in time plus appropriate State of Charge - SoC) given the small scale of the project. iv) Another challenge is to quantify and clearly price services such as congestion management.
Grid Motion, France, 2017-19 Large scale, privately funded demonstration of V1G[8] and V2G – to deliver cutting-edge consumer insights with respect to frequency response, arbitrage etc.	Vehicles used: 15 Peugeot iOn or Citroen CZERO Charging location: work Charge point: V2G - Enel 10 kW DC, (V1G is using bidirectional Nuvve 18 kW AC chargers) Customer offer: free charger	Frequency response, arbitrage through intra day and day ahead trading, reduced ToU charges through time-shifting.	i) Study conducted to demonstrate commercial feasibility and to break down barriers for market access of DERs in France. ii) It was found that regulatory barriers exist relating to introduction of diverse, distribution level kW-scale resources i.e. minimum participation limits to trade and access frequency market. iii) Battery min./ max. usage was found to be dependent on the specific model of the car.
ACES project, Denmark, 2017-20 The Across Continents Electric Vehicles Services (ACES) project aimed to analyse the technical and economic benefits of EV integration in the	Vehicles used: Nissan LEAF (30 kWh) and E-NV200 (24 kWh). Charging location: Commercial (research centre) Charge point: bidirectional commercial	Frequency response, constraint management, peak shaving.	i) By considering a combination of Japanese charging patterns and Danish driving behaviour, it is derived that a 100% EV penetration would determine an evening peak coincidence factor[9] equal to 40% for a 3.7 kW charge level. ii) Frequency control could yield a profit of more than 1000 Euros/ year per EV with a 10 kW bidirectional charger. However, the efficiency of the bidirectional charger, market conditions, and price per service could severely reduce the profit. iii) The additional wear due to the intense

[8] V1G or smart charging refers to the ability to dynamically control the time and magnitude of charging power from the power source to the EV.

[9] Coincidence factor is the peak of a system divided by the sum of the peak loads of the individual components of the system.

island of Bornholm in Denmark, augmented by real usage patterns, grid data and field testing for across continents replicability.	chargers (ENEL-Endesa 10 kW) Customer offer: Not known		bidirectional power flow during grid provision, such as frequency control does not drastically degrade the battery. iv) A generic power system should be able to accept a primary power reserve of up to 50% from EVs without any major problems. v) 100% EVs in Bornholm (equal to 17,500 vehicles) could lead to an equivalent storage of 700 megawatt-hours (MWh) of electricity.
KEPCO project, South Korea, 2015-17 Project was part of a broader Vehicle Grid Integration program laying the technical groundwork for the smooth roll-out of EVs in Korea.	Vehicles used: 2 Hyundai (28kWh 1xAC 1xDC); 1 i10 (20 kWh AC) Charging location: Commercial (research centre) Charge point: 2 x AC 6.6kW charging / 3.3kW discharging. 1 x 10kW DC Customer offer: Not applicable - no real customers; Program was conducted by researchers.	Time-shifting for energy use.	i) Response within 10 seconds achieved. ii) Tested EVs responded to various types of demand response signals with more than 95% accuracy.
JUMPSmart MAUI, Hawaii, 2012-16 Part of a broader smart grid project seeking to study renewable energy, electric vehicles, energy storage, and controllable loads in Maui, Hawaii.	Vehicles used: Nissan LEAF Charging location: Home Charge Point:6kW Hitachi DC Customer offer: Free charger provided	Frequency response, peak shaving	i) 80 families using the vehicles 'normally', typically plugging in on return from work. This limited the diversity of use cases and restricted the time periods during which V2G could be provided. ii) Hitachi developed its own integrated Demand Management System (DMS) to create a charging schedule so as to fill up the gap between the estimated power generated by renewable energy and load of the next day. iii) Export was limited to 1kW, even though 6kW was modelled. Interconnection standards were onerous and specific to Hawaii. iv) It was challenging to forecast vehicle behaviour and hard to get new users onboard. v) Provided demand response through V2H, EVs were found to be fast and flexible and when combined with other resources were observed to be very valuable to the grid.

INVENT project, California, 2017-20 Large-scale trial to test V2B integration on UCSD campus' 45 MW microgrid with significant amount of solar energy generation.	Vehicles used: 2 Mitsubishi Outlanders (12 kWh); 7 Nissan LEAFs (24-30 kWh); 9 Chevy Bolts/ BMW i3s/ Daimler Smart/ Model 3/ LEAF Charging location: Commercial (university campus) Charge point: 9 AC Nuvve PowerPorts (18kW) 9 DC Hitachi (6 kW) Customer offer: Free charger, parking and electricity	Peak shaving, frequency regulation, reduction of peak demand	i) Battery Degradation: V2G does cause some additional degradation but it is much smaller than that experienced through driving behaviour, particularly on account of regenerative braking. Potential damage depends on service, with full charge/ discharge cycles being the worst. ii) It can be a challenge to assess the amount of power that can be provided to the market with a lower number of EVs. iii) Unexpected damage to test vehicles, and drivers' different trip schedules can make planning harder. iv) Plug-in time can be optimised by assigning convenient parking locations to project drivers.

Source: Data sourced from Everoze and EVConsult (2018), Marinelli et al.(2020), and Das and Deb (2020)

Principles for designing policy on V2G

For a technology in its incipient stages that requires both a long gestation period as well as continued collaboration across sectors and domains, it might be imprudent at this stage to prescribe clear, actionable policy solutions. Broad principles that can guide future policy design should be much more useful at this point in time. The following are some principles which may be kept in mind when thinking about V2G in India's context.

Optimising relay of price signals and other information to all parties

It has been established that ToU tariffs are essential for the full gamut of opportunities emanating from V2G to be realised. It is important for regulators and power providers in the country to experiment with, and subsequently implement, dynamic pricing strategies (Das & Deb, 2020). ToD tariffs specifically designed for EV charging could be a good starting point. Capacity could be slowly developed for real-time pricing for which there is currently no precedence in the country. Later on, innovative pricing models may be explored depending on the forecasted demand and usage patterns. These could include critical peak pricing, among others. Efforts should also be made to ensure stability and predictability in the regulatory and pricing regime considering the fact that States enjoy substantial freedom to decide their rates and pricing categories. For optimising monetary gain for EV owners, aggregators need a whole range of data about their usage patterns, route timings and battery status. For coordinated communication to achieve these ends, a certain degree of maturity in AI, Internet of things (IoT), telematics, etc. is essential. Attempts should be made to expedite applications of these technologies in EV-related domains.

Adopting robust communication standards

Standardised communication protocols may be adopted for better communication between the stakeholders. India could explore OpenADR or the V2G focused ISO 15118-20 (De Bruyckere, 2021). Additionally, the Central and State Nodal Agencies should "mandate all smart charging service providers to install OCPP-compliant charging equipment and create a central cloud-based backend system (Charging Station Management System) adhering to the OCPP communication protocol, to enable real-time charging data transfer to a Central Management System, remote modification of charger configuration, and remote charging session control" (Das & Deb, 2020).

Decentralising the power sector

India needs to aim for aggregation in its power sector and structure ways to better integrate the multiplicity of DERs that are staking a claim to complement the capabilities of the grid. This includes being more open to involving smaller players and third party aggregators in the supply of power and designing hybrid market models for DISCOMs wherein both DISCOMs and third party aggregators can compete for customers. Appropriate regulatory design should "enable all these entities to compete on a level playing field and maximise opportunities to reap both wholesale and distribution benefits" (Das & Deb, 2020). Secondly, network operators should service specifications with V2G in mind. This could include priming the grid to allow for frequency response injection through V2G with a response time of under two seconds; optimally balancing power and duration for successful reverse flow of power through V2G enabled EVs, among others.

Treating EV owners as prosumers

EV owners could enjoy a regulatory level playing field with rooftop solar generators with them being treated as both consumers as well as producers. Necessary regulatory amendments may be made to broaden the concept of a Virtual Power Plant (VPP) and similar net/ gross metering standards may be devised to integrate the energy being supplied by EVs to the grid. Adequate measures will also be needed to be taken on applicable rates for electricity export, settlement period, limit on system capacity, communication capability, etc. (Das & Deb, 2020).

Encouraging EV aggregation through an emphasis on MaaS

Aggregation is necessary to achieve scale in V2G operations. Many services discussed in the preceding sections only make financial sense if provided at scale through aggregated portfolios of EVs. Aggregation usually occurs at the level of the charging service provider. While aggregation of demand is currently prohibited by existing regulations, an in-principle argument can be made for its exploration. This should give an opportunity to design portfolios by clubbing EVs depending on the nature of the vehicle, their availability, route patterns and timings etc. Aggregators could then make use of these use cases to customise offers and co-optimise several value stacks for their different sets of customers (Jones et al., 2021). This could be done by integrating mobility-as-a-service (MaaS) models to incentivise EV users through multiple avenues (Everoze & EVConsult, 2018). Additionally, aggregators could specifically target services where V2G adds substantial value such as - "(1) for services where location matters; (2) locations with surplus solar capacity; (3) markets with high peak pricing or charges; and/or (4) for longer duration services" (Everoze & EVConsult, 2018).

Prioritising phased investments in infrastructure, R&D and upskilling

There are obvious infrastructural investments that need to be made for grid and technology upgradation to implement V2G at scale. A sudden capacity upgradation is neither desirable nor financially feasible for India. It should instead explore financing opportunities through long period debt instruments or other such means to avoid asset liability mismatch scenarios and undertake a phased upgradation of its infrastructure. More immediate attention is needed on conducting pilots in Indian conditions, building regulatory and technological awareness on the issues involved, studying impact of high ambient temperatures on battery health, and finally, upskilling the workforce with a focus on grid engineering, mechatronics, telematics etc.

Encouraging OEMs to embrace bidirectional charging

OEMs will need to be more welcoming of bidirectional charging possibilities. Most OEMs do not produce the batteries they configure into their EVs, with battery manufacturers providing a set number of charging cycles on their battery warranty thereby limiting the scope for continual charging and discharging necessitated under V2G. Currently, OEMs are predisposed to invalidating the warranty if their EV is used for bidirectional charging. This needs to change. Additionally, OEMs may be mandated to provide bidirectional charging capability in their vehicles. As a lesson from the City-Zen project, slow starters may be compulsorily installed to limit the effects on a sudden voltage inrush (Everoze & EVConsult, 2018). Since slow charging for V2G is a likely next frontier for the technology as it provides better support in providing grid-stability and reliability through V2G, OEMs must try to aim for hardware maturity especially with respect to AC chargers to bring down the cost and increase efficiency. Finally, EV batteries with at least 1C capacity should be prioritised for larger vehicles such as cars.

Incentivising EV owners to participate in V2G

This is perhaps the biggest challenge for large-scale V2G implementation. In addition to the measures mentioned earlier, attractive subscription offers, charging top-up services as well as high price differentials between charging and supplying energy back to the grid may be probed. When developing the incentive mechanisms, existing interconnection rules should be kept in mind and additionally, the rights of customers must be protected – they should be given the ability to override signals when participating in such programmes, in which case they would have to forgo any monetary benefit they would have otherwise received (Das & Deb, 2020). Countries across the world are experimenting with a range of demand side incentives to boost EV sales. These include special parking spots, lane preferences, congestion charge waivers etc. (Hall et al., 2020). Perhaps at a later stage when V2G becomes more mainstream, such exclusive and affirmative measures may be considered for V2G-enabled EVs as well.

Widening the participatory base and ensuring an equitable burden of costs

Modelling by Cenex (2020) has shown that "using V2G for revenue generation is mainly advantageous for use cases where vehicles are plugged in for long periods of time whilst not charging. The average customer with plug-in rates of 30% could capture just a quarter of the annual revenues from TSO [Transmission System Operator] services compared to those able to plug in 75% of the time." India must try to set up as many bidirectional charging points as possible, especially at strategic locations such as parking spots at shopping complexes and office spaces. Of course, this would require technological maturity in slow charging (AC) as well as massive investments, but the potential benefits outweigh the costs. The private sector can be enthusiastically involved in this process. The overall participatory base can be further widened by making necessary changes to institutionalise an ancillary services market for arbitrage, frequency response etc. Care should also be taken to make sure that costs entailed in V2G setup and operations are not disproportionately borne by either the customers or the grid operators.

Way forward

With reducing battery prices and better overall cost parity of EVs, India's segment-wise EV penetration profile can safely be forecasted to be suitable for implementing V2G at scale in the future. By implementing differential electricity tariffs; ensuring improved coordination between grid and distribution outlets; creating an ancillary market for services such as frequency regulation, voltage control, and black-start, India could position itself favourably for the oncoming V2G revolution.

What is needed is an adequate understanding of the issue through pilots designed specifically for Indian conditions. Additionally, there is scope for greater research to estimate and quantify potential benefits of V2G adoption for India. The next few years should hopefully witness an upsurge of interest in this domain both through work by researchers working in mobility and energy domains as well as through B2B collaborations to unearth the economically productive forces that can be leveraged through V2G. Collaboration is also the need of the hour among all stakeholders involved in operationalising V2G. Only well calibrated, coordinated and collective efforts can help India fully realise V2G's potential.

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www.ola.institute

mobilityinstitute@olacabs.com

https://twitter.com/OlaMobilityInst

https://medium.com/@mobilityinstitute

Author:

Yash Narain

Yash is a Researcher at OMI. He holds a Master's degree in Political Science from Delhi University and is an avid mobility policy enthusiast.

Contributors: Shilpi Samantray, Aishwarya Raman

Peer Reviewers: Chandana Sasidharan, Principal Research Associate, Alliance for an Energy Efficient Economy (AEEE); Ishan Bhand, Research Consultant, Alliance for an Energy Efficient Economy (AEEE).

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