In cooperation with

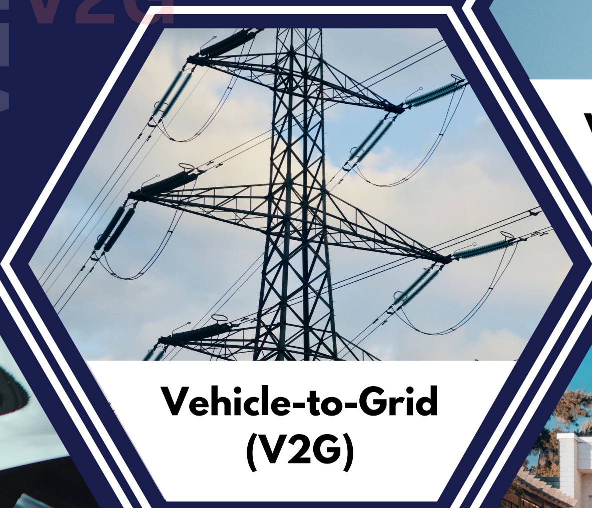
Government of India
Ministry of Power
Central Electricity Authority

GRID INTEGRATION LABORATORY
IIT BOMBAY

EXECUTIVE SUMMARY

IMPLEMENTATION OF VEHICLE-TO-EVERYTHING (V2X) IN INDIA

A study conducted by
Indian Institute of Technology (IIT) Bombay
In cooperation with CEA, Ministry of Power



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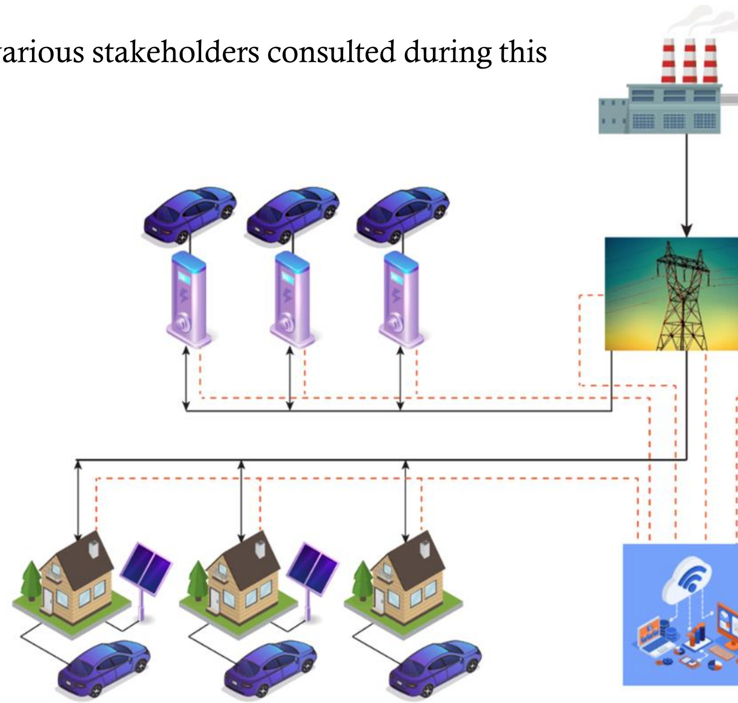

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सत्यमेव जयते

आज़ादी का अमृत महोत्सव

FOREWORD

India has committed to be net-zero by 2070. All sectors including transport sector need to take action to achieve this. Electrification of the transport sector which is one of the major source of carbon emission, will play a critical role in decarbonizing the transportation energy vertical and in achieving net-zero target of the country. With the ambitious targets of Electric Vehicle (EV) adoption, India has initiated several measures to electrify the transport sector through different initiatives, such as, the National Electric Mobility Mission Plan (NEMMP) 2020, Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, and Electric Vehicle (EV) policies at State/UT level.

Adequate charging infrastructure and its grid integration plays a critical role in seamless adoption of electric vehicles. While EV integration can introduce several challenges in the grid, particularly at distribution system level, such as impact on voltage, increased losses, congestion, power quality and unbalancing issues, the EV charging technology can be potentially managed to not only minimize the grid impacts, but also exploited to support the the grid in several ways. With the increased penetration of EVs, for example, battery storage in BEVs, which remains largely underutilized across the vehicle segments (2/3/4 wheeler and heavy duty vehicles including E-buses), can be utilized for various grid management/support services. Vehicle-to-grid (V2G) that allows reverse power flow from battery of EV to the grid and vice versa, has enormous potential to open up a range of potential grid support services, such as, increased uptake of renewable energy (RE) generation, improve grid management, and efficient grid operation. However, since V2G technology is relatively new, it is important to understand how in the Indian context, V2G can be put to the best use to the advantage of electricity grid and the overall Indian EV ecosystem.

I am pleased to note that realizing the pressing need to analyze and understand how EVs through bidirectional power flow can be implemented in India, IIT Bombay has undertaken a timely study on "Implementation of Vehicle-to-Everything (V2X) in India" which is a first of its kind study in India. Through this study, Grid Integration Lab at IIT Bombay has developed two reports focussing on a detailed technical review, market survey of V2X technology and its relevance in Indian EV ecosystem, and techno economic analysis backed recommendations for V2X adaption in Indian context. The study has comprehensively analyzed various V2X technologies (V2G, V2H, V2B, V2L etc.) and its applications in Indian context, identified key gaps in adoption of V2X technology in India, and offered a way forward for adoption of V2X in India through various recommendations backed by detailed techno-economic analysis. I am sure this study through its quality reports on this important topic of V2G and other V2X applications will be beneficial to different stakeholders with useful inputs for various V2X applications including regulatory aspects for V2G adoption in India. This study is expected to serve as a constructive reference/input for grid integration of V2G technology and its grid connectivity standards for Indian grid.

I congratulate IIT Bombay for conducting this timely study on an important topic of implementation of V2G in India and publishing its findings through two technical reports. I also appreciate the effort of Shri Ashok Kumar Rajput, Member, Central Electricity Authority and his team's association in preparation of this report.

(Ghanshyam Prasad)

Prof. Willett Kempton,
Professor at the University of Delaware in the College of Earth, Ocean and Environment, and in the Department of Electrical and Computer Engineering.

FOREWORD

Decarbonizing transportation is an essential part of addressing the challenge of climate change. India, consistently with its carbon emission reduction targets, is achieving electrification of the transportation sector toward the targets for EV adoption set both at the National and State level. However, adequate charging infrastructure and the integration of charging with the electric grid will be crucial to achieve the transition to sustainable mobility. Although EV charging load introduces challenges in the grid, the smart use of EV charging infrastructure can unlock a new potential of the mobility sector to benefit grid management. Vehicle-to-grid (V2G) has a great potential to help in efficient and optimal grid management, particularly, in India which has one of the largest power grids, and is also one of the largest vehicle producing countries. Since India is at an early stage of EV adoption, it is well positioned to plan adoption of V2G in the country through the contemporary understanding of technical, regulatory and policy interventions.

I am pleased to note that the Grid Integration Lab of IIT Bombay has undertaken this important and timely study of “Implementation of Vehicle-to-Everything (V2X) in India”, and I believe that the two reports of this study will serve as a reference document for V2X implementation in India. I hope that the findings of this study will inform Government and Industry stakeholders in India, and create momentum for policies facilitating adoption of V2G and other V2X applications in the Indian EV ecosystem. India has so much talent, a large market, and low-cost IT and manufacturing infrastructure, all of which can drive V2X forward.

At University of Delaware, I got the original idea of using electric vehicles to support the electric grid, published in 1997, and colleagues and I have been developing it ever since. Little did we know that our idea 26 years later would develop into the concept of Vehicle-to-Everything (V2X) and find its way to India, one of the largest car markets in the world.

I congratulate the IIT Bombay team for this interesting study. I am looking forward to following the progress of V2X in India and I wish all the best luck in making V2X a success in India and beyond.

Prof. Willett Kempton

केन्द्रीय विद्युत विनियामक आयोग
CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

Indu Shekhar Jha
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Foreword

Climate change driven global temperature rise is having far reaching consequences, particularly on the modern human civilisation. India has embarked on the path of renewable energy (RE) based sustainable transition of power sector towards clean energy-based system with ambitious targets set for RE integration by 2030. In COP26 held in Glasgow, India committed to reaching net-zero carbon emission target by the year 2070. However, in order to achieve carbon neutral target, besides power sector, it is critical to address carbon emissions from other energy sectors as well. Transportation sector contributes approximately 23% of total carbon emissions, thereby highlighting the pressing need to decarbonise the transportation sector. In order to address carbon emission from the transportation sector, India has already started electrifying its transportation sector across all the vehicle segments for which sector coupling between power and transportation sectors is crucial. Forum of Regulators, in its report on 'Energy Storage and Electric Vehicles' (Nov 2022) have examined the regulatory challenges and recommended enabling policy and regulatory framework for effective and smooth integration of EVs with the Indian grid.

E-mobility of the transportation sector introduces new demand with unique characteristics to the power system through Electric Vehicle (EV) charging load. EV charging load can result in various challenges in the grid operation, but also has a significant potential to help in grid management and increased update of RE integration. Therefore, to address challenges of EV integration and unlock opportunities from EVs & charging infrastructure, it is important to have a deeper understanding of EV integration enabled through constructive studies.

I am pleased to note that Grid Integration Lab IIT Bombay has undertaken an important and first of its kind study in India "*Implementation of Vehicle-to-Everything (V2X) in India*" that analyses implementation of emerging EV integration technologies including Vehicle-to-Grid (V2G) technology in the Indian grid. This study provides technical, regulatory and policy recommendations for seamless adoption of V2X in India derived from primary research including techno-economic analysis of V2X implementation, secondary research and stakeholder consultations. Since India is at early stage of EV adoption, the outcome this study documented in two reports is expected to help the relevant stakeholders including OEMs, policy and regulatory decision makers in taking timely and effective measures for implementation of V2X in Indian EV ecosystem.

I congratulate IIT Bombay team for taking up this timely study on V2X implementation in India and documenting its outcome in two important reports for the benefit of all the stakeholders of EV ecosystem. I am sure the outcome of this study will benefit different stakeholders including DISCOMS, Grid operators, regulatory bodies, relevant OEMS, research community and think tanks.

(Indu Shekhar Jha)

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Foreword

The consequences of climate change are far-reaching, impacting not only the environment but also posing significant risks to human health, food security, water resources, and biodiversity. Urgent and coordinated efforts are imperative to mitigate greenhouse gas emissions, adapt to the changes already underway, and foster international collaboration to build a resilient and sustainable future. To tackle the climate issue, in the recently concluded COP26 in Glasgow, India committed to reaching net-zero target by the year 2070. To curtail carbon emissions, in addition to ambitious renewable energy integration targets, India has set ambitious targets for reducing emissions in the transportation sector.

The global transportation landscape is evolving, with electric mobility emerging as a key player in redefining how we envision transportation, energy, and environmental stewardship. Access to electricity and mobility are two of the most significant markers for defining modern life. Vehicle to Everything (V2X) is the epitome of the coupling of this transportation and the other energy carriers. With V2X enabling the use of the energy storage unit of the EV for different applications, EVs can be used as flexibility resource for better grid management. The study "Implementation *of Vehicle-to-Everything (V2X) in India*" undertaken by Grid Integration Lab IIT Bombay is an important and timely study for advanced development of Indian EV ecosystem, particularly in the space of Vehicle-to-Grid (V2G) adoption in India. This first of its kind study in India delves into the intricate web of factors shaping the V2X landscape, from requirements in hardware to the need for capable charging infrastructure supporting V2X, and policy & regulatory interventions required for seamless adoption of the technology in India. It explores the economic implications, policy frameworks, and the dynamic interplay between manufacturers, EV users, and decision-making agencies, all contributing to the V2X ecosystem.

Importantly, the study provides information on different applications of V2X such as Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H), Vehicle-to-Building (V2B), Vehicle-to-Vehicle (V2V) and Vehicle-to-Load (V2L), their enablers, requirements and potential benefits. The study also provides a much-needed techno-economic analysis of different V2X applications in an Indian context, that can help Indian stakeholders in estimating the potential of V2X.

I extend my congratulations to the IIT Bombay team for conducting this much needed study of V2X and preparing the two important reports for the benefit of different stakeholders of EV ecosystem. Their collective efforts have produced a valuable resource that not only elucidates the current state of electric vehicles but also paves the way for informed decisions and strategic planning in our pursuit of a sustainable and greener future. I am sure these study reports will serve as a catalyst for ongoing discourse, innovation, and cooperation as we collectively strive to usher in an era where electric vehicles play a central role in driving us towards a more sustainable and harmonious coexistence with our planet.

(Alok Tandon)

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1. Background of the project

Climate change is regarded as the "greatest peril contemporary humanity has ever faced," with far-reaching consequences across numerous sectors. India is already witnessing the plights of climate change, with pollution killing almost 2.3 million in 2019 alone[1] and a 55% increase in deaths due to extreme heat between 2000-2004 and 2017-2021[2]. India is the world's 4th largest emitter of CO_2 and the transportation sector is the third largest emitter in the country.

To tackle the climate crisis, globally the transportation sector is gradually transitioning from fossil fuel powered Internal Combustion Engine based vehicles to electric vehicles (EVs). In addition to reduced emissions, the demand for EVs is being driven by national efforts/targets aimed at reducing reliance on oil imports.

Charging EV batteries introduces additional stress on the electricity distribution grid. As the proportion of EVs in the distribution system rises, the impact of EV charging on distribution system may become significant.

While EV integration can introduce several technical challenges, such as impact on voltage, increased losses, congestion, power quality and unbalancing issues, the EV charging technology can be potentially managed to not only minimize the grid impacts,

[1] BBC, "Lancet study: Pollution killed 2.3 million Indians in 2019", May, 2022. https://www.bbc.com/news/world-asia-india-61489488
[2] BBC, "India heatwave: High temperatures killing more Indians now, Lancet study finds", October, 2022. https://www.bbc.com/news/world-asia-india-63384167

but also exploited to help the distribution system management in several ways. V1G (managed charging), which can control the charging rate of vehicles to ease stress on the grid, and V2X, which is the bidirectional flow of electricity from/to the vehicle, are the two approaches for managing EV charging load.

V2G has a significant potential to support distribution and transmission system through various services. Such methods can help utilities address the issue of network reliability in the event of high EV uptake. EV batteries which technically have bidirectional power flow can be used for different applications.

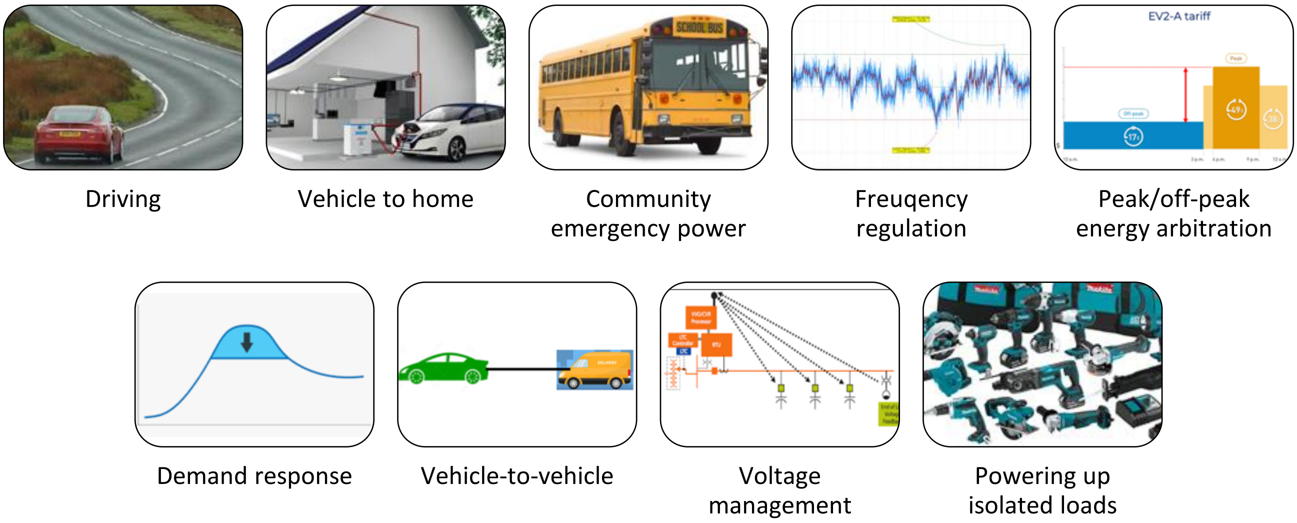

Figure 1:1: Different applications of EV battery

Bidirectional EV charging has enormous potential since these capabilities would open up a range of potential grid support services, such as, support increased uptake of renewable energy (RE) generation, improve grid management, and promote more efficient grid operation. Bidirectional charging allows EV mobile storage units to be utilised as a vital grid and energy management resources. Considering the ambitious targets of EV adoption in India and net zero target of the country, there is a need to understand the V2X technology, its integration with the grid, and optimal use of V2G for sustainable and seamless transition to electrified transportation sector. In this backdrop, this study is focused on V2X technology and its adoption in Indian EV ecosystem with primary focus on seamless integration of V2X technology with the electricity grid in Indian context, while considering both technical and economic feasibility.

2. Overview of the study

2.1. Aim of the study

The aim of this study was to conduct a detailed analysis with high impact/ quality reports that can supplement decision making agencies both at Central including State Government level, distribution system operators, transmission system operators, planning and regulatory agencies and other stakeholders (EV industry etc.) to frame, adapt, and/or revise policies, regulations, technical charging standards, and communication protocols related bidirectional EV charging (V2X including V2G), tariffs, interconnection regulations, etc.

2.2. Objectives of the Study

This study is primarily focused on a detailed technical review and market survey of V2X technology, and techno economic analysis backed recommendations for V2X adaption in Indian context. The review of V2X technology includes detailed review of bidirectional charging enabled chargers and EVs. The system architecture which involves the interaction between different stakeholders of V2X, the communication infrastructure, and the roles and responsibilities of different stakeholders for implementation of different V2X use cases has been also critically analyzed in this study. These use cases include the utilization of V2X for peak load management, increased renewable energy (RE) integration, voltage and frequency support, vehicle to home (V2H), vehicle to building (V2B), vehicle to load (V2L), etc.

A detailed analysis, for gaining an understanding of the technical know-how of V2X has also been performed in this study, followed by techno-economic analysis to determine viability of V2X in the Indian context. This study is expected to play a key role in determining techno-economic gaps including the policy and regulatory issues that need to be addressed for smooth V2X roll-out in India. The study finally provides recommendations to promote the growth of V2X in the Indian EV ecosystem.

2.3. Organization of the study reports

The main outcome of the study is documented in a series of two technical reports and structured as shown inFigure 2:1. Each of the reports cover different aspects of V2X in a structured manner for effective, organized and easy dissemination of the study outcome.

- **Report 1:** Fundamentals of Vehicle-to-Everything: Technology, Enablers and Challenges
- **Report 2:** Techno-Economic Analysis and Recommendations for V2X Implementation in India

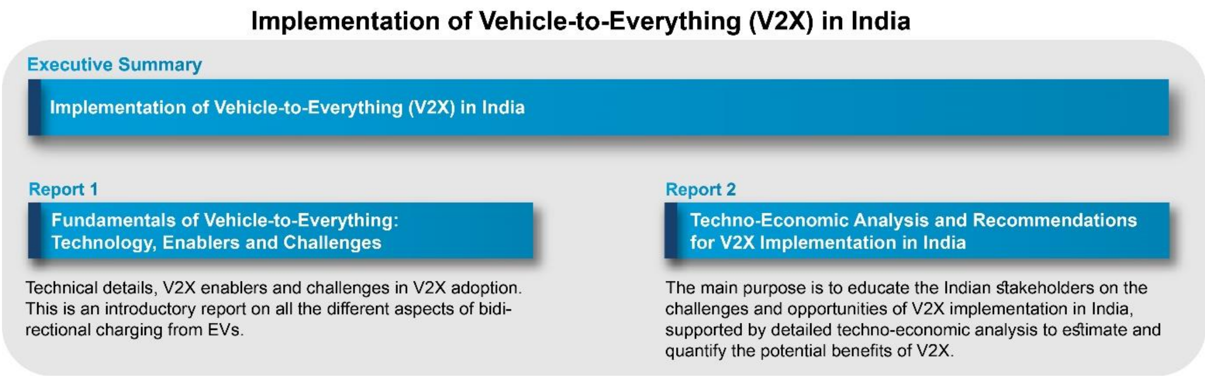

Figure 2:1 Project Document Structure

3. Concept of Vehicle-to-Everything

Vehicle-grid integration (VGI) refers to the technologies, policies, and strategies for EV charging which enable controlling the EV charging in a manner that benefits the grid while still meeting the EV users' mobility requirements. Vehicle-to-Everything (V2X) is a part of VGI and is a technology that enables use of EV batteries, sitting idle and not being currently used for mobility purposes, to provide valuable power back to 'everything'. Here 'everything' or 'X' can be the electricity grid, a home, a building, independent loads or even other EVs as shown inFigure 3:1. Depending on to whom the EV is giving the power to, different terms have been coined. This flexibility provided by EVs can prove to be a significant value addition for the grid operators.

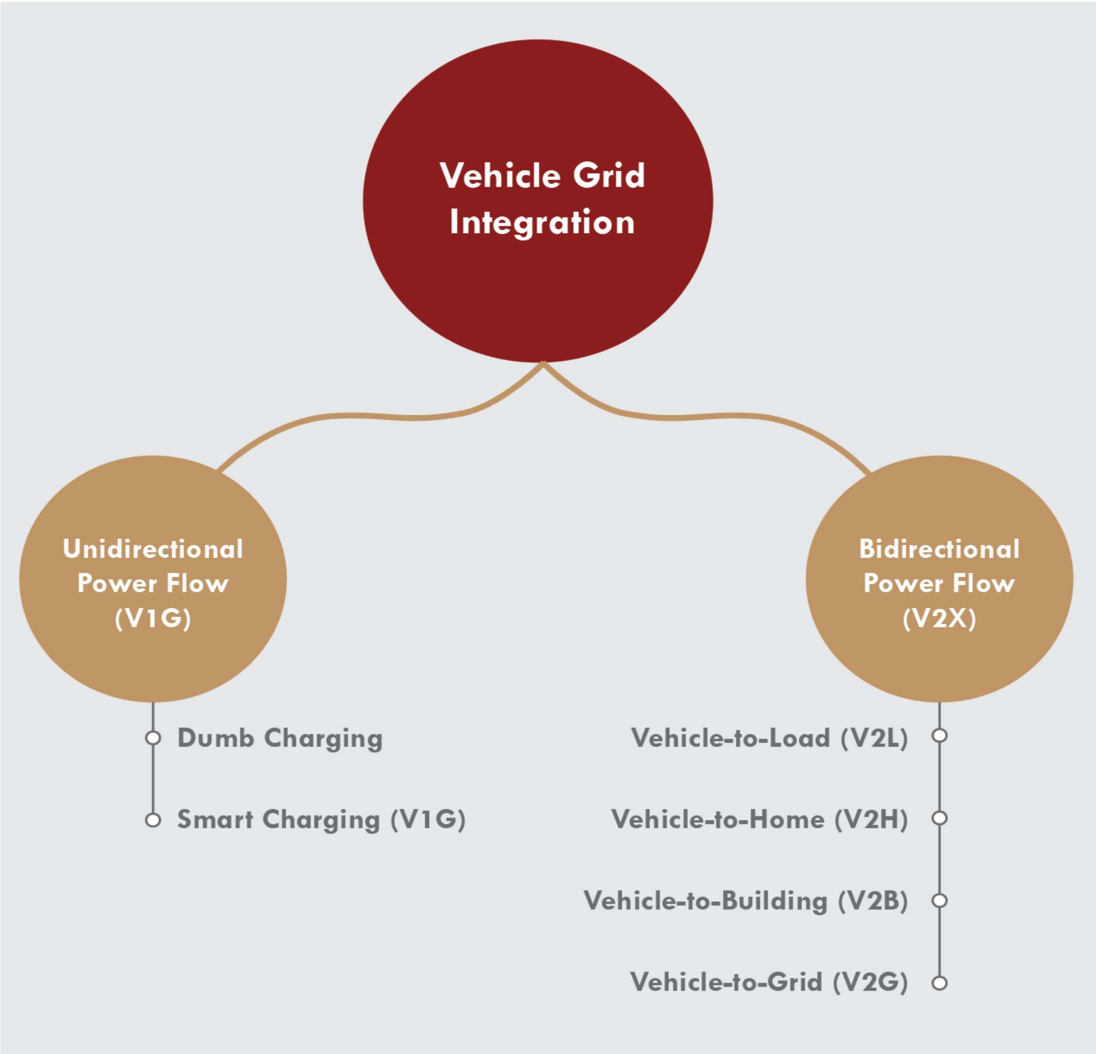

Figure 3:1: Vehicle-grid integration

3.1. Vehicle-to-grid (V2G):

Electrical vehicle grid integration (VGI) services are essentially concerned with managing EV charging such that the effect on the electrical grid is minimised. V2G is an expansion of the VGI idea in that, in addition to controlling charging, the energy stored in the EV battery is provided back to the grid when needed.

The essential characteristic of V2G is that it takes an existing asset, the EV battery, and transforms it into a comparably rated grid-connected stationary energy storage unit. Hence, technically, a V2G EV can provide all services that any other storage unit can provide as shown inFigure 3:2. While an individual EV may not have enough energy to meaningfully help the grid on its own, aggregating a large number of EVs can function as a considerably big energy storage unit. V2G capable EVs can thus provide services to both the transmission and distribution networks, based on the aggregation size and control capabilities.

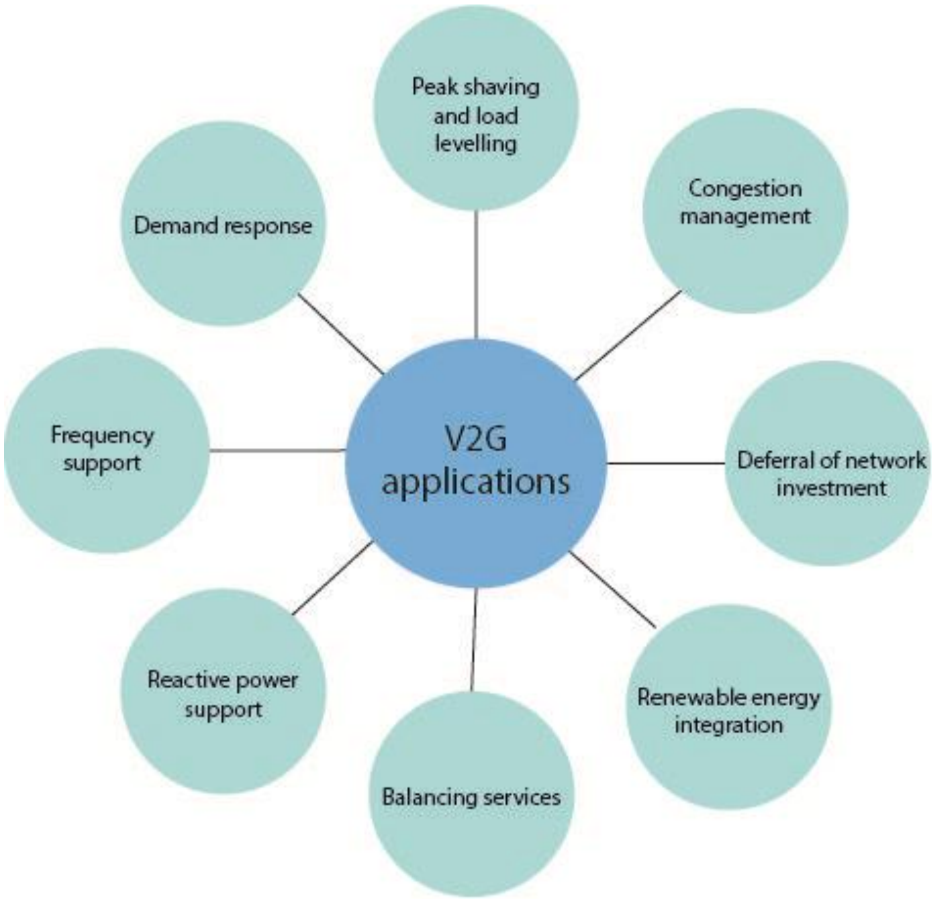

Figure 3:2: V2G applications

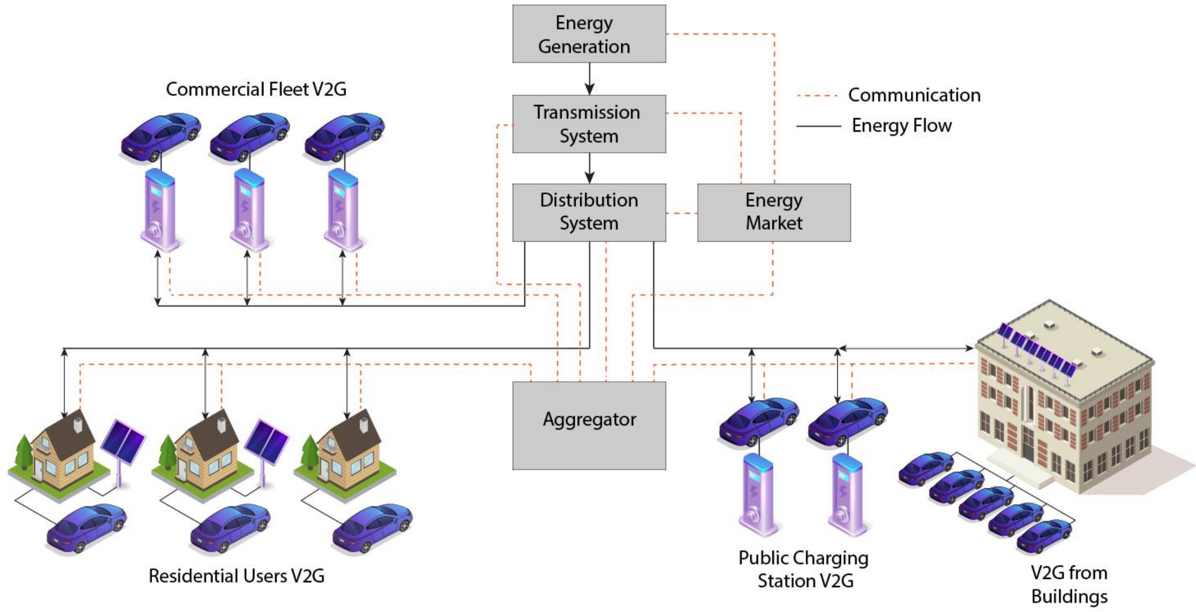

Figure 3:3: V2G system architecture

3.2. Vehicle-to-home (V2H)

Vehicle-to-home (V2H) allows the EV user to utilize the stored energy in the EV to be used as a power source for the home. Here, the energy in battery storage unit of the electric vehicle is used to provide power to the home in case of emergency, or for behind-the-meter optimization purposes. It is similar to having a portable energy storage device that can be used for different services by the EV user.

Figure 3:4: V2H system[3]

[3] Gaton, Bryce, "We're building a new house. What do we need for bidirectional EV charging?", The Driven, May 13, 2019. https://thedriven.io/2019/05/13/were-building-a-new-house-what-do-we-need-for-bidirectional-ev-charging/

3.3. Vehicle-to-building (V2B)

Similar to V2H, in vehicle-to-building (V2B), instead of a single EV supplying a house, a fleet of EVs are supplying a larger building such as an office, malls etc. The fleet of EVs can be used for the behind-the-meter optimization or as emergency back-up power. By lowering the peak load, permitting distributed generation, and enabling building self-consumption, the widespread use of V2H and V2B enhances the grid's stability and dependability[4].

Figure 3:5: Fleet of Nissan Leafs being used as V2B resources to power an office in Japan[5]

3.4. Vehicle-to-load (V2L)

Vehicle-to-load (V2L) is one of the simpler applications of V2X, where the EV battery is used to power standalone loads. It allows the EV user to power 220V appliances such as electric drills, induction hotplate, etc. or 12 V devices directly from the EV. For this, some EVs have three pin plugs already available in the EV body while in others an adapter is needed to connect to the charging port of the EV and draw power. It is relatively simple as the inverter inside the EV is used to supply power to the outlets provided.

3.5. Vehicle-to-vehicle (V2V)

In vehicle-to-vehicle (V2V) an EV with bidirectional charging capability is used to charge another electric vehicle. These can be used for the following,

- To power isolated vehicles as emergency backup.
- Share power at charging stations. Here the vehicles are not directly connected to each other. Instead, both of them are connected to the charging station. The goal

[4] Nazari, Shima, Francesco Borrelli, and Anna Stefanopoulou. "Electric vehicles for smart buildings: A survey on applications, energy management methods, and battery degradation." Proceedings of the IEEE 109, no. 6 (2020): 1128-1144.
[5] Inhabitat. https://inhabitat.com/nissan-leaf-vehicle-to-home-technology-powers-office-buildings-in-japan/

here is to charge EVs while not exceeding the total power capacity of the charging station.

3.6. Value estimation for V2X

V2X implementation requires multi stakeholder collaboration and so for its success, the different involved stakeholders need enough financial benefits to stay engaged in this business. Even prior to V2X application, different business are involved in practices such as raw material extraction, manufacturing of EVs, chargers, assembly etc. thereby deriving lucrative revenue. The different value streams just for developing and establishing an electric vehicle ecosystem has been given in Figure 3:6. For all of the different identified value streams, a unique business opportunity could be created.

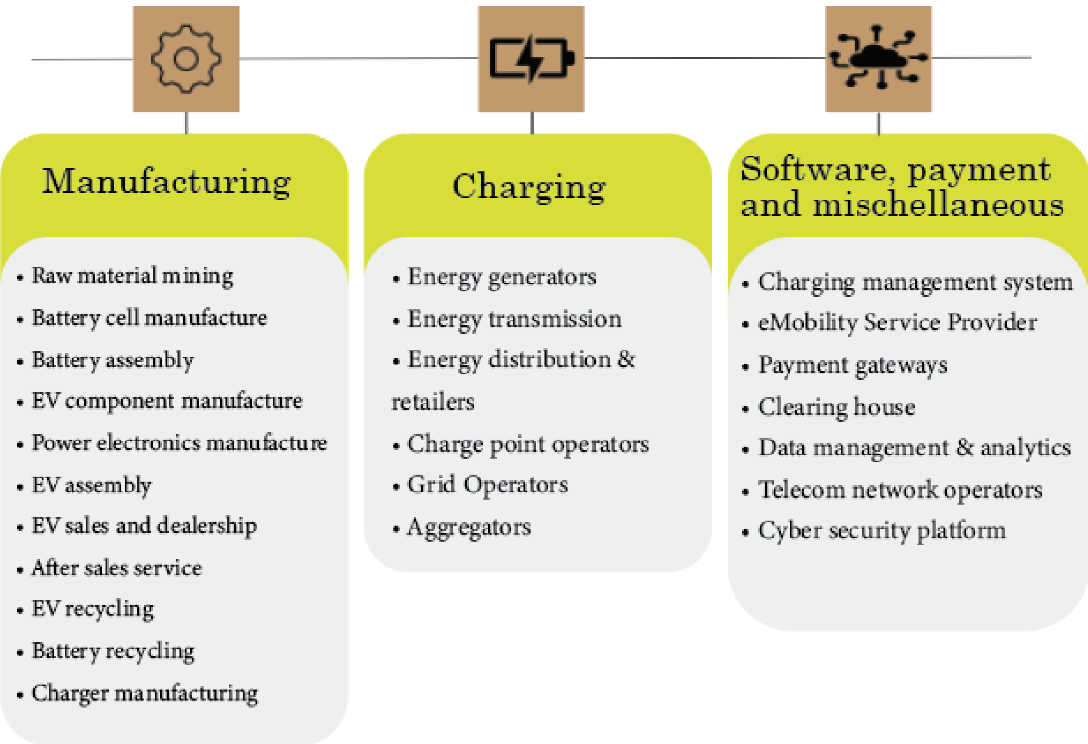

Figure 3:6: Value stream in electric vehicle ecosystem

As the underlying technology of V2X is similar to other lithium-ion battery storage systems (BESS), so technically V2X can also participate in most applications where BESS can be used. Different stakeholders can derive value at different stages of the V2X application. Stakeholders such as energy generation entities, transmission and distribution utilities, charge point operators (CPOs) can extract value directly by sale of energy. The EV users extract value when they get financial benefits (in form of cost minimization or revenue generation) by performing the V2X application. The aggregator and the charging management system (CMS) facilitates this V2X application, enabling them to create revenue opportunities. At the same time the transmission system operator (TSO), distribution system operator (DSO) and market operator acquires a new resource for grid support services, which can help them better manage the grid, thereby leading to value addition. Finally, to facilitate the entire operation a robust and reliable communication network needs to be developed and maintained and thus providing value to telecom operators. The different entities and stages where the stakeholders can extract value using V2G have been summarized in Figure 3:7.

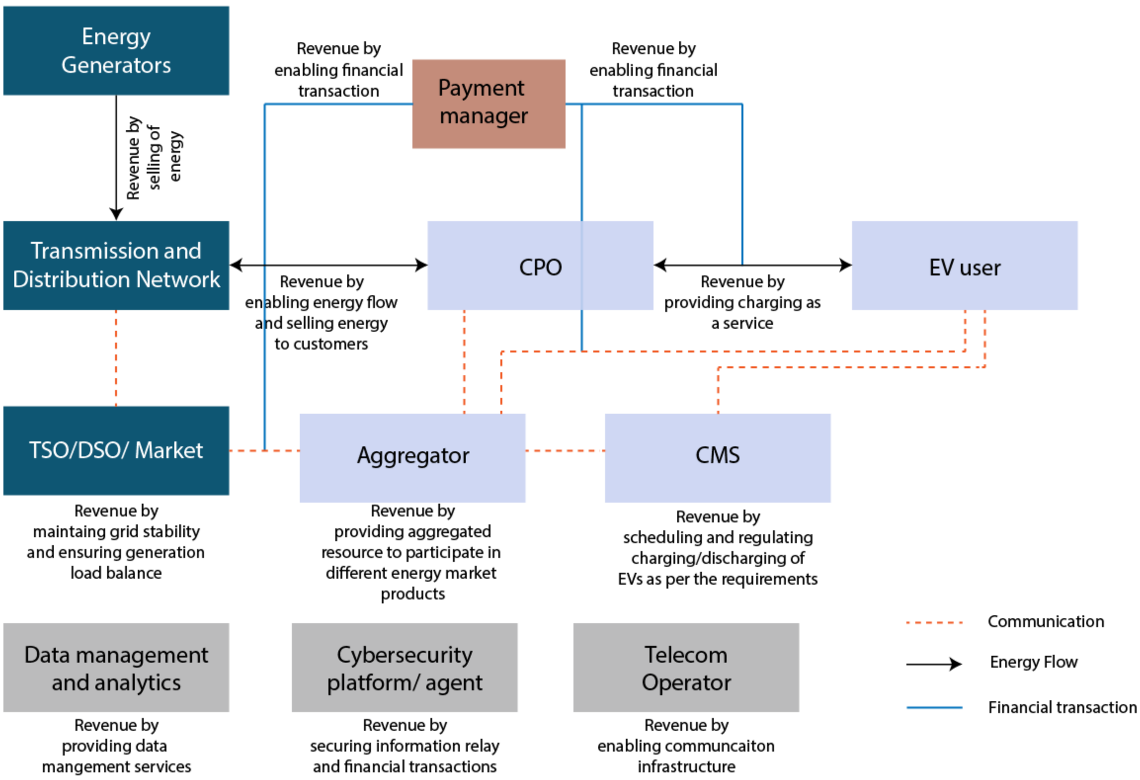

Figure 3:7: Value chain of V2G application

3.7. V2X enablers

There are different requirements to enable V2X applications.

3.7.1. Hardware requirements

One of the crucial requirements for V2X are bidirectional EV chargers. Bidirectional EV chargers allow power flow in both the directions. The bidirectional charger mainly comprises of bidirectional AC to DC converter followed by a bidirectional DC to DC converter[6]. A bidirectional power factor correction circuit is used between these two converters. A basic block diagram of a bidirectional EV charger is shown in Figure 3:8.

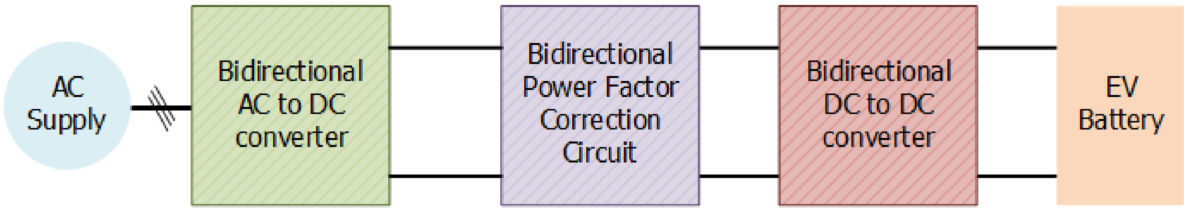

Figure 3:8: Block diagram of bidirectional EV charger

While the potential benefits of bidirectional charging are numerous, the EVs that offer the capability today remain limited. The key difference between V2X and non V2X cars is the battery management system (BMS). In order to facilitate V2X, the BMS should be capable of handling the extra functionalities that arises because of V2X. This may add to the complexity of the BMS.

3.7.2. Communication and data set requirement

The successful implementation of V2X applications is highly dependent on the communication of accurate, necessary, and reliable data. Depending on the V2X application different sets of data (under different spectrum of use cases such as grid management, authentication etc.) needs to be communicated among the different stakeholders/entities involved. To facilitate the communication of the data there are different communication protocols in place as given in Figure 3:9

[6] Yuan, Jiaqi, Lea Dorn-Gomba, Alan Dorneles Callegaro, John Reimers, and Ali Emadi. 2021. "A Review of Bidirectional On-Board Chargers for Electric Vehicles." IEEE Access. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2021.3069448.

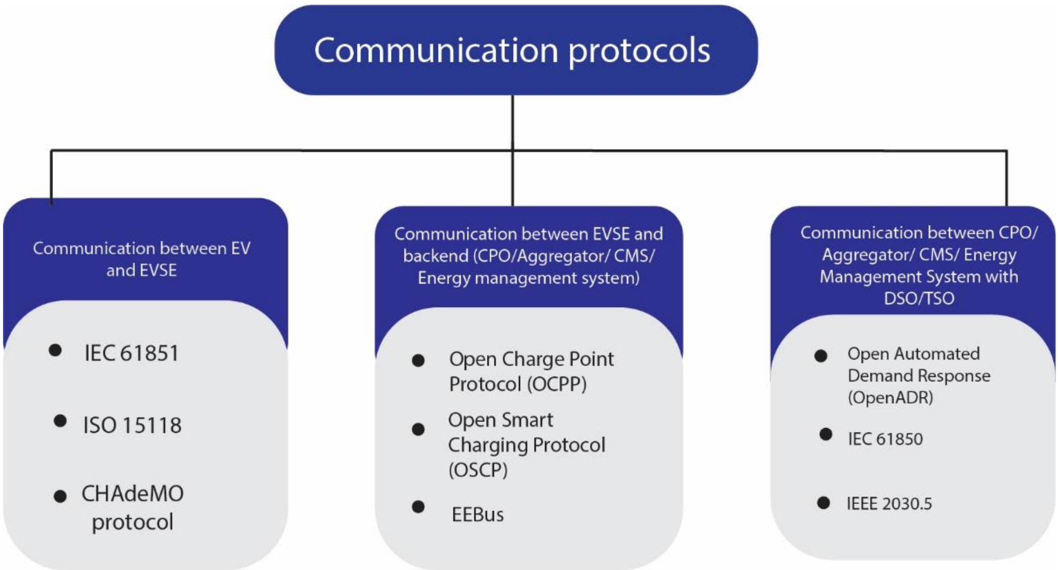

Figure 3:9: Some of the common Communication protocols for V2X (non-exhaustive list)

3.7.3. Role of aggregator

One of the crucial enablers of V2G are aggregators. Their core function is to aggregate multiple EVs and present them as a single entity participating in the different services. They help in managing the risks both on behalf of the grid operators and market players and the and use customers. Different stakeholders can play the role of an aggregator depending on their existing business models. Some of the likely stakeholders that can play the role of an aggregator are,

- Energy retailers
- Demand response providers
- Charge point operators
- E-mobility service providers
- Fleet management and vehicle leasing companies
- Vehicle OEMs

4. Techno-economic analysis of different V2X applications

In this project, to have a deeper understanding of the impact of V2X in an Indian context, a techno-economic analysis was performed. The analysis showed that smart charging of EVs (V1G) can reduce the negative impacts of EV integration to a large extent. However, the value provided in terms of flexibility and grid support is much higher for V2G when compared with V1G. V2G resources have the capability to provide reactive power support, significantly benefiting the grid operator and other commercial customers. V2G resources can also provide frequency support to the grid and generate revenue for the EV owners. The study also found that V2G can help the DISCOMs in load shifting and peak reduction which can reduce the need for network upgradation, thus bringing much value to DISCOMs. V2G resources were also found to help increasing the penetration of renewables in the system thereby significantly helping in the greening the grid. Further, the role of EVs in reducing the cost of electricity for EV owners were also explored in the study. It was determined that V2H and V2B can significantly increase the potential savings that individual residences or buildings can achieve by transitioning to V2H/V2B from dumb charging. However, in some scenarios the high capital cost of DC bidirectional chargers[7] may reduce the commercial viability of the services under current regulations. The details of the techno-economic study can be found in Report 2 of the study.

4.1. Reactive power support

One of the critical requirements for maintaining system health is the availability of adequate reactive power reserves. DC EV chargers can be configured to enable the four-quadrant operation and help in reactive power compensation for the network[8]. This enables the DC chargers to provide reactive power irrespective of whether the charger is being used for charging. The distribution system modelled to study reactive support services from EV is shown in Figure 4:1, which is a real urban LV distribution grid in India. The distribution network comprises 1279 lines, 1293 busbars, 12 transformers and 450 loads. Each of the 12 transformers is an 11/0.4 kV transformer feeding a total

[7] AC bidirectional chargers would be significantly cheaper than DC bidirectional chargers and can increase the commercial viability of V2G services.
[8] N. Mehboob, M. Restrepo, C. A. Cañizares, C. Rosenberg and M. Kazerani, "Smart Operation of Electric Vehicles With Four-Quadrant Chargers Considering Uncertainties," in *IEEE Transactions on Smart Grid*, vol. 10, no. 3, pp. 2999-3009, May 2019, doi: 10.1109/TSG.2018.2816404.

connected load of 2.57 MW. The downstream network of the transformers has been defined as separate feeders, as given in Table 4.1.

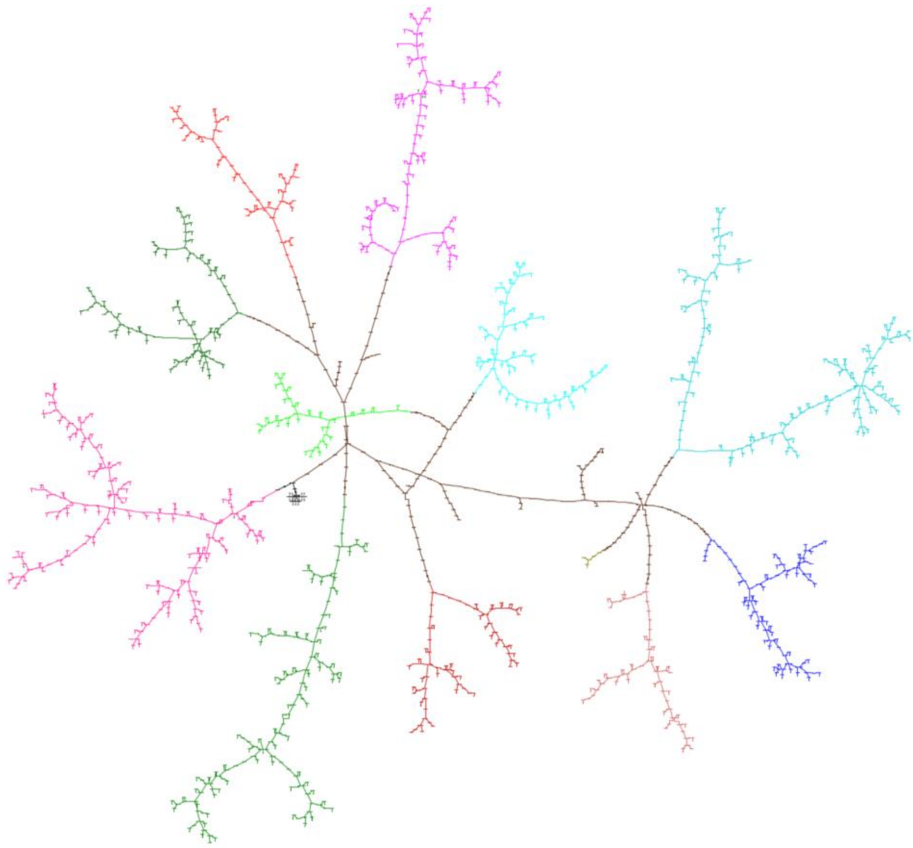

Figure 4:1: Indian LV distribution grid considered for study

Table 4.1: Feeder characteristics

Name	Number of customers	Infeed transformer rating (kVA)
Feeder 1	1	3000
Feeder 2	77	945
Feeder 3	21	400
Feeder 4	37	400
Feeder 5	26	400
Feeder 6	40	500
Feeder 7	22	315
Feeder 8	64	400
Feeder 9	11	250
Feeder 10	35	315
Feeder 11	50	630
Feeder 12	66	630

For reactive support, 8 DC Fast Chargers (DCFC) were installed at 6 different public charging station (PCS) locations, with characteristics given in Table 2.

Table 2: Characteristics of PCS

Name of charging station	Rated capacity of each charger (kW)	Number of chargers	Rated power of PCS (kW)
PCS 1	50	1	50
PCS 2	150	1	150
PCS 3	50	1	50
PCS 4	150	1	150
PCS 5	50	3	150
PCS 6	50	1	50

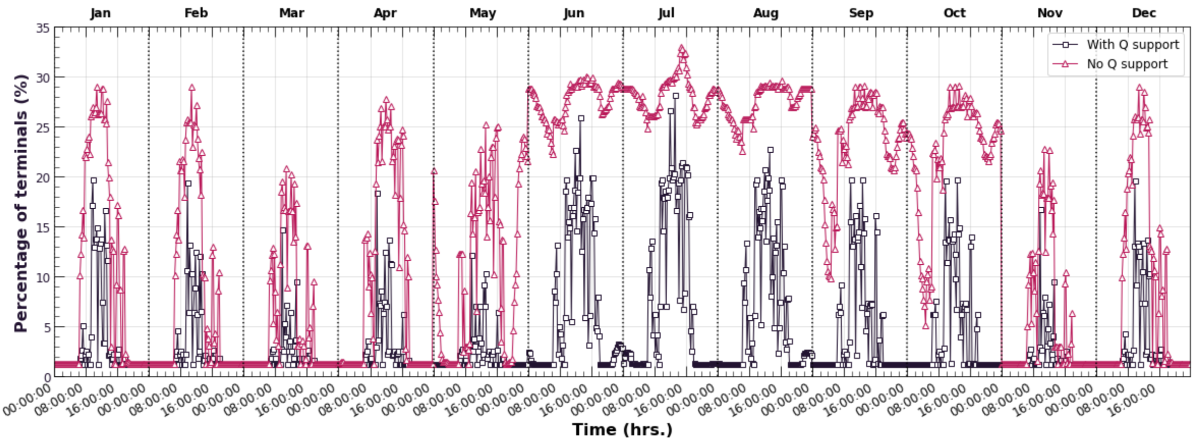

Figure 4:2: Percentage of terminals that do not comply with voltage limits of 0.9-1.05 p.u, considering non-EV loads to have a power factor of 0.9

The voltage across the distribution system improved significantly with the provision of reactive power from the DCFC. The percentage of buses that do not comply with the voltage thresholds of 0.9-1.1 p.u. have been illustrated in Figure 4:2. Reactive power support from PCS significantly reduces the number of buses that do not comply with the minimum voltage requirements.

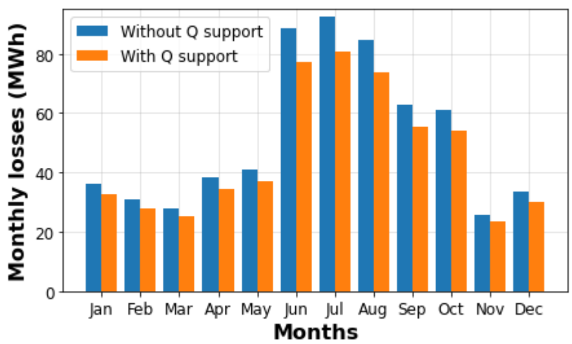

Figure 4:3: : Monthly transmission and distribution losses for non EV load power factor of 0.9

The improvement in the voltage profile also lead to reduction in the transmission and distribution losses in the system as shown in Figure 4:3.

4.1.1. Economic analysis on the provision of reactive power support

For performing a cost-benefit analysis of reactive power support from EVs, two different scenarios have been considered,

- Cost savings due to reduced reactive power consumption from the transmission network
- Cost savings due to reduced losses in the system

The Indian Electricity Grid Code (IEGC) recommends that it is preferable to generate reactive power locally near the load-centric zones rather than draw reactive power from the transmission network. In line with this inclination, to discourage reactive power draw, a reward/incentive scheme based on reactive power drawal/injection has been adopted in India. In line with IEGC, the potential savings that can be made by the DISCOM from this 1kV feeder itself ranges between INR 3-4.2 lakh annually as can be seen in Figure 4:4.

The annual savings due to a reduction in transmission and distribution losses is around INR 5,22,173 when the non-EV loads have a power factor of 0.9 and INR 70,103 when the power factor is 0.95.

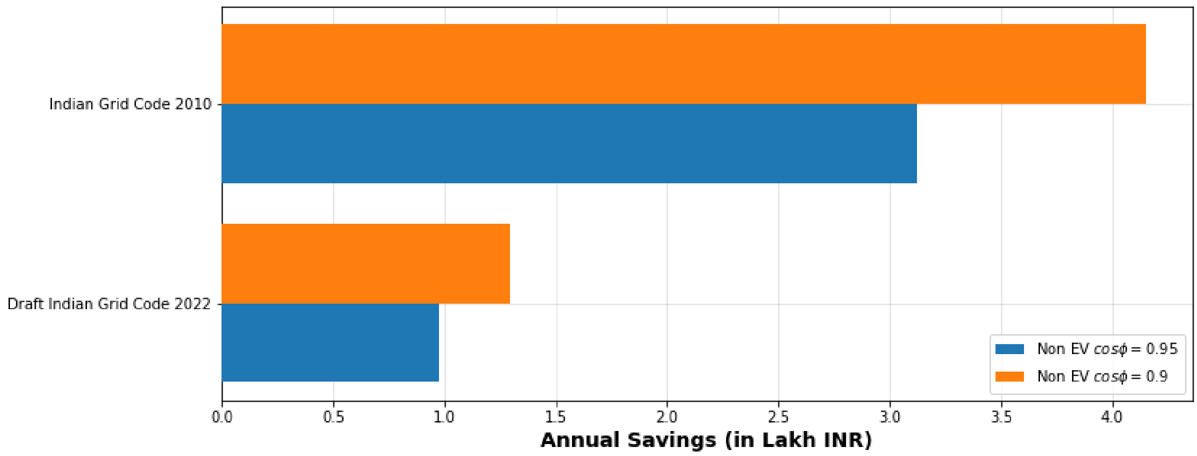

Figure 4:4: Annual savings when providing reactive power support from PCS

4.1.2. PCS as power factor control for industrial customers

For illustrating the benefits that an EV charging station can provide to a large customer, a case study of a food processing plant in Delhi has been considered. Food processing plants are typically low-power factor (high-reactive power) consumers. As can be seen from

Figure 4:5, without any support from the charging station, the power factor of the industry was pretty low, between 0.6 to 0.8, which led to high reactive power drawal from the grid, between 200 kVAr to 800 kVAr. With the provision of reactive power support from the EV charging station, the reactive power requirements were met locally by this captive reactive power resource and the drawal from the grid was significantly reduced.

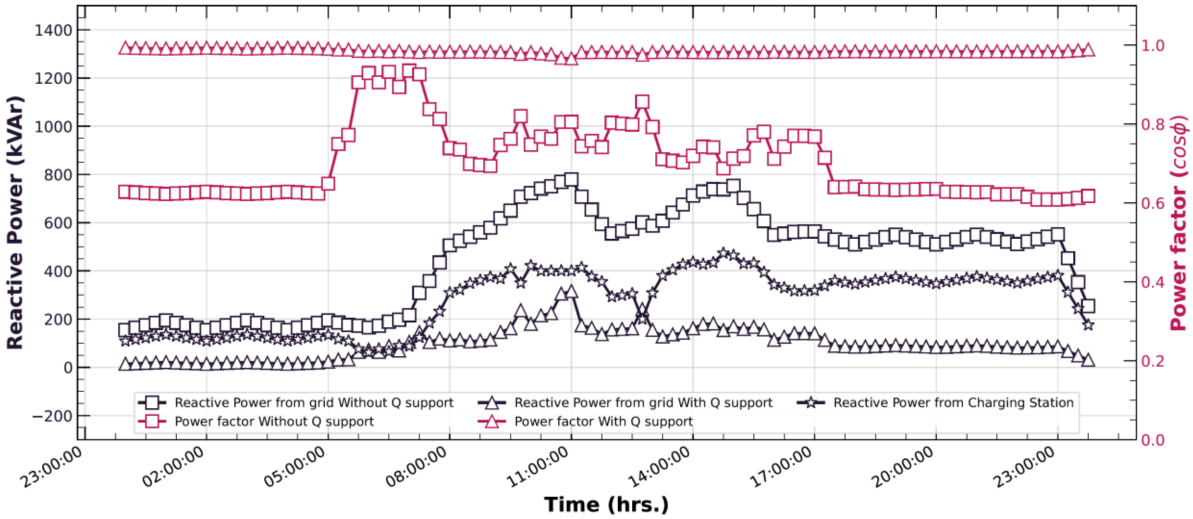

Figure 4:5: Reactive Power and Power factor of the industry with and without support from the charging station

Industrial customers are typically billed for both the energy drawn and the maximum demand. The demand charge is calculated based on the maximum kVA drawn by the plant for a 15-min time slot in the month, and the energy charge is based on the kVAh consumed by the plant during the month. By utilizing the reactive power support from the charging station, the industry can reduce its monthly demand charges from INR 3,28,687 to INR 3,07,596, i.e. a savings of INR 21,090 per month or INR 2,53,087 per year. Looking at the energy savings, the charging station can reduce the daily energy bill from INR 1,24,725 to INR 1,01,789, i.e. a saving of INR 22,936 per day or INR 71,79,234 per year can be made

4.2. Frequency support

The controllable and fast-acting nature of EVs also lends itself suitable for providing frequency support services. In this study, the EVs are being used to provide frequency regulation service. The role of frequency regulation service is to maintain the system frequency within pre-specified frequency bands during normal operation and is one of the ancillary services procured by the system operators generally through energy markets. Frequency regulation is the injection or withdrawal of active power by resources in response to regulating signals sent by the system operator.

Real frequency data (histogram of frequency data shown in Figure 4:6) measured at IIT Bombay campus has been used in this analysis. The measurements have a sampling frequency of 50 Hz. i.e. a sample is collected every 20 ms. During a three-day period when the measurement was carried out, for 22.53% of the time, the frequency was below 49.9 Hz. In contrast, for 0.92% of the period, the frequency was above 50.1 Hz. This characteristic has been accounted for during the modeling of the frequency regulation controller.

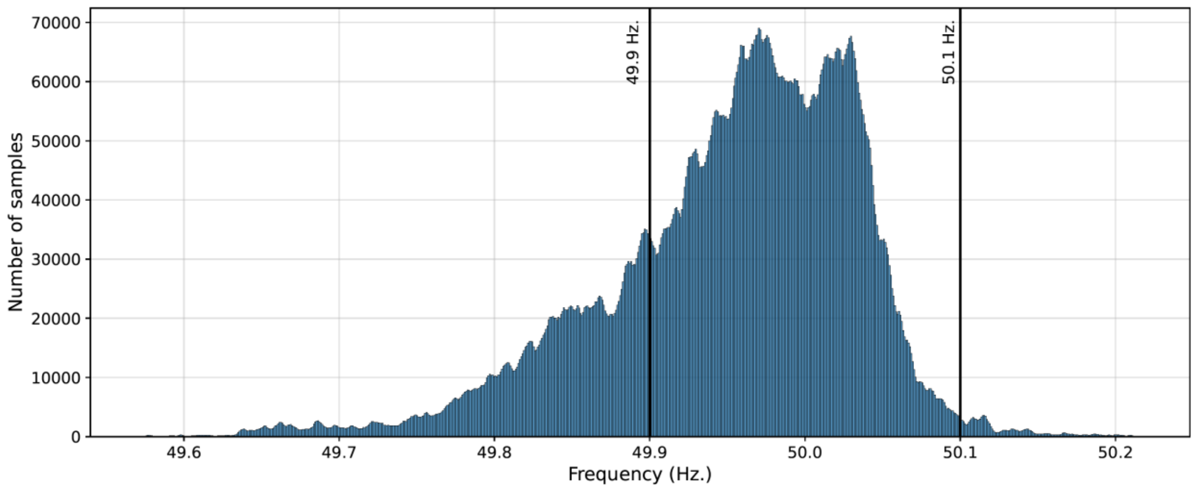

Figure 4:6: Histogram plot of the frequency measurement data

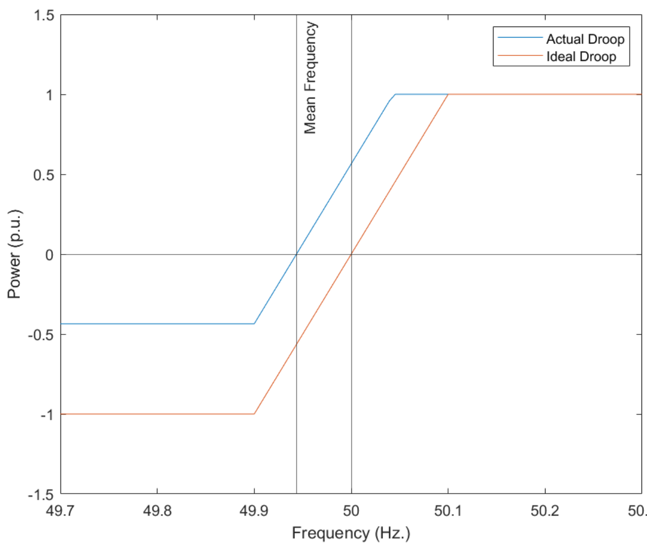

Figure 4:7: Frequency response characteristic

The frequency regulations response of the EVs have been shown in Figure 4:7. When the frequency goes below 50 Hz. the EVs reduce their charging power or start discharging depending on the droop curve shown in Figure 4:7 and vice versa during over frequency periods. As shown in Figure 4:6, the frequency in the Indian grid often lies lower than the nominal frequency band, so the actual droop (actually used for regulation) has been introduced which is an offset of the actual droop, so that the EV is not continuously discharged.

For this case study, it has been considered that the EV aggregator has 1000 vehicles registered under it willing to provide the needed regulation. The study is conducted for a simulation period of 30 days, where each EV has a random travel distance.For the execution of regulation service, the aggregator measures the local frequency and commands the EVs to respond to the frequency based on Figure 4:7. However, a minimum bid amount of 1000 kW has been set, which implies that if the regulation reserve is less than the value, the aggregator is not allowed to provide the service. It has also been considered that the EVs start participating in the service from midnight 12 AM until the EVs plug out the following morning.

It was observed that EV users can earn a sizeable amount of revenue by participating in frequency regulation services. The mean annual revenue for an EV user is INR 9,000, INR 16,300 and INR 23,500 for participating factors of 0.4, 0.7 and 1, respectively[9]. There is a trade-off between the revenue earned by the EV user and their SoC level. If the EV user wants higher profit for participating in regulation service, they would be subjected to higher SoC swings, which may hamper the travel requirements of the user. However, some EV users have earned up to INR 15,700, INR 28,200 and INR 40,700 for the three participating factors, respectively. The amount earned is related to the number of times an EV user participated in the service. Figure 4:8 shows the revenue earned by the EV user against the number of charging events by the EV user. It shows that with increasing charging events, the revue earned by the EV user from participating in regulation services increases[10].

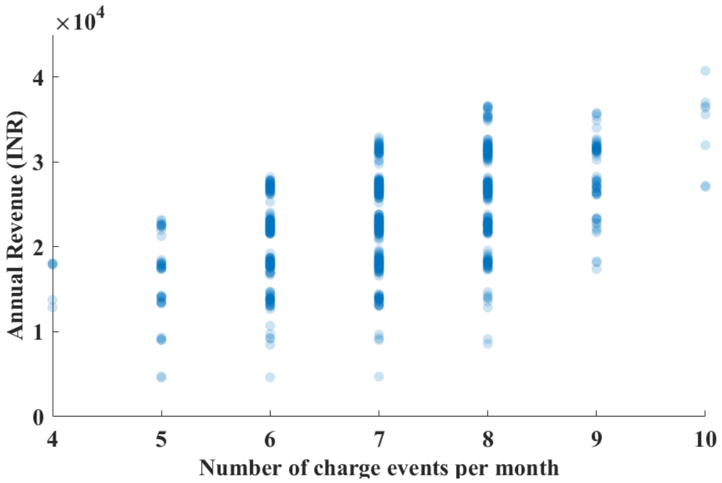

Figure 4:8: Annual revenue earned by the provision of frequency regulation service vs the number of charging events undertaken by the EV user in a month (shown for participation factor of 1)

[9] The participation factor signifies the proportion of the charging/discharging power that the EV user has allocated for regulation service purposes. A participation factor of 0.4 implies that the EV user has allocated 40% of their charge/discharge capability to provide regulation service.
[10] If EVs are allowed to participate in ancillary services, the EV user can also plug in their vehicle even if there is no charging requirement, just to provide these services and earn revenue. This change of attitude has not been factored in this study.

4.3. Vehicle-to-home

Private EVs are utilized for the purpose of mobility for only about 5% of the time, which typically consists of the daily commute between workplace and home and, at times, additional travel during the weekends. Therefore, EVs stay parked for about 95% of their time, during which they can be deployed for other services by connecting them to the grid, home, building, other local load etc., thereby utilizing the underlying storage more effectively, efficiently and economically. Three different cases were studied for the techno-economic analysis of V2H,

- Case 1 – V2H with only grid supply
- Case 2 – V2H with grid supply and rooftop solar PV
- Case 3 – V2H with grid supply, rooftop solar PV and battery storage

A single household with an EV with 40 kWh battery, a 2 kWp rooftop solar PV system and a 8.7 kWh battery have been considered in this study. Regarding the electricity tariff, the base price is assumed to be INR 4.12/kWh with a surcharge of INR 1.1/kWh during peak hours and a rebate of INR 1.5/kWh during off-peak hours. The daily load profile of a single house considered for this study is shown in Figure 4:9.

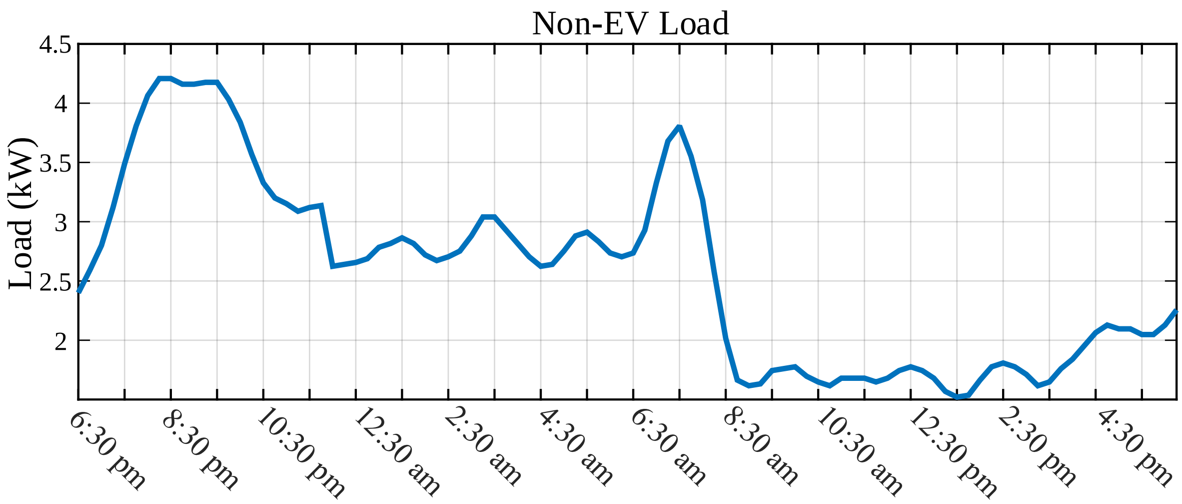

Figure 4:9: Representative non-EV load curve for a single house

It can be observed from Table 3, that the energy cost per day decreases as we add multiple energy sources to the system. The energy cost per day is lowest in the case with both rooftop solar PV system and the stationary battery storage system. The energy cost per day is highest for the case with only grid supply. On the contrary, when the capital cost of additional components is included, the annual levelized cost is highest for the third case, i.e., grid supply with rooftop solar PV system and stationary battery storage system.

Table 3: Comparison of three cases in terms of operational and annual levelized costs

Case	Operational Cost (INR/day)	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	149.98 (EUR 1.76)	54743.18 (EUR 642.37)
Case 2: Grid Supply + PV System(2kWp)	111.71 (EUR 1.31)	53693.90 (EUR 630.06)
Case 3: Grid Supply + PV System(2kWp) + Battery Storage (8.7kWh)	104.93 (EUR 1.23)	149067.18 (EUR 1749.20)

Taking into consideration the cost of EV chargers, the economic viability of investing in V2H or V1G chargers are provided in Table 4. From the table it can be observed that comparatively lower capital investment needed for V1G chargers and their potential savings, makes utilization of V1G chargers for residential users the most viable. Even transition from dumb charging to V2H capable chargers provide economically viable opportunity.

Table 4: Difference between increment in capital expenditure and NPV of savings considering 10 years of operational lifetime

	Only Grid	Grid + PV	Grid + PV+ Battery
V0G-V1G	₹ 1,73,788.44	₹ 1,73,809.93	₹ 1,73,799.19
V0G-V2H	₹ 14,554.23	₹ 14,581.10	₹ 14,581.10
V1G-V2H	₹ -1,59,234.21	₹ -1,59,228.84	₹ -1,59,218.09

4.4. Vehicle-to-Building

The differentiating factor between V2H and V2B is that in V2B, the number of EVs is generally higher, which provides more flexibility resources. Also depending on the building type (office/shopping mall, residential complex, etc.), the characteristic load profiles, the EV availability periods can have marked differences leading to differences in the potential revenue earning opportunities. Similar to V2H, here too three cases have been considered as mentioned below,

- Case 1 – V2B with only grid supply

- Case 2 – V2B with grid supply and rooftop solar PV
- Case 3 – V2B with grid supply, rooftop solar PV and battery storage

Three different building types were considered here – an office, a shopping mall and a residential building each with their own load characteristics. The operational and annual levelized cost of the three buildings are provided in Table 5, Table 6 and Table 7. It can be observed that for all the three buildings, the operational cost was lowest with PV and energy storage (Case 3) followed by building with PV system (Case 2). However, if the capital expenditure is also taken into consideration, Case 3 has the highest annualized cost, followed by Case 1. Although the capital expenditure for Case 2 is higher compared to Case 1, the savings made on the operation cost is able to pay for the added expenditure.

Table 5: Operational and annual levelized cost for the 3 considered cases of office building

Case	Operational Cost (INR/day)	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	14,130.98	51,57,809
Case 2: Grid Supply + PV System (30 kWp)	11,824.46	45,09,622
Case 3: Grid Supply + PV System(2kWp) + Battery Storage (250 kWh)	11,773.22	73,02,700

Table 6: Operational and annual levelized cost for the 3 considered cases for shopping mall

Case	Operational Cost (INR/year)	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	2,59,375.02	9,46,71,882
Case 2: Grid Supply + PV System (125 kWp)	2,51,461.77	9,25,91,081
Case 3: Grid Supply + PV System(125kWp) + Battery Storage (1000 kWh)	2,50,066.08	10,33,28,297

Table 7: Operational and annual levelized cost for the 3 considered cases for residential building

Case	Operational Cost (INR/year)	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	19,574.17	71,44,573
Case 2: Grid Supply + PV System (75 kWp)	14,826.22	58,96,093
Case 3: Grid Supply + PV System(75kWp) + Battery Storage (300 kWh)	13,847.28	89,12,769

Further, different comparisons were made to arrive at the optimal design of V2B. Two different scenarios for energy input have been considered, one with only grid and second with an addition 50 kWp rooftop solar PV. Further, different number of vehicles have been considered. Another consideration made is the contracted demand of the property. The difference between the increment in capital expenditure and the NPV of the annual savings due to the respective switch to V2G/V1G from V0G considering 10 years of operational life is given in Table 8. The cells shaded in red indicate that the capital investment is higher compared to the net savings, while the cells shaded in green indicate that the net savings is higher. It can be observed that with lower number of vehicles, switching to bidirectional charging shows a positive difference. This is because the capital incurred for 40 bidirectional chargers becomes much higher compared to the net savings. However, it can also be observed that when the limitations on the maximum contracted demand are removed[11], the total savings are significantly increased making the business case financially viable. Shifting from V0G to V1G is always sensible as the potential savings outweighs the capital investment across all cases. But investment in bidirectional charging needs a more nuanced approach. When there was a restriction on the maximum power capacity, increasing in number of EVs and EV chargers showed a negative trend in the economic viability. On the other hand, when there was no restriction on the maximum demand, addition of bidirectional charging showed a positive trend in economic viability. So, while deciding on the addition of bidirectional chargers in the building, the available contracted power capacity is one of the important parameters that needs to be taken into consideration.

[11] This is a valid assumption in the case of large consumers as residential complexes, large offices, shopping malls etc. These kind of buildings generally have a separate 11 kV/400 V transformer, and can so technically use as much power they wasn't as long as the transformer is not overloaded.

Table 8: Difference between increment in capital expenditure and NPV of savings considering 10 years of operational lifetime

	Total contracted demand restricted to 200 kW						Unrestricted total contracted demand					
	Only Grid			Grid + PV (50kWp)			Only Grid			Grid + PV (50kWp)		
Number of EVs	**10**	**20**	**40**	**10**	**20**	**40**	**10**	**20**	**40**	**10**	**20**	**40**
V0G →V1G	-1,00,763	9,88,561	23,42,477	-1,33,275	9,53,363	24,20,110	7,65,367	30,79,475	70,06,348	7,47,358	30,48,884	70,82,546
V0G →V2G	19,29,255	12,76,849	-1,02,04,165	-91,215	-10,41,815	-62,95,681	27,92,682	33,64,661	67,73,950	7,90,208	10,53,560	44,20,350
V1G →V2G	20,30,019	2,88,287	-1,25,46,643	42,059	-19,95,179	-87,15,791	20,27,315	2,85,185	-2,32,397	42,849	-19,95,323	-26,62,196

5. Gap analysis for the adoption of V2X

Implementation of V2X in India is however laced with different challenges and barriers. The nature of these challenges includes regulatory challenges, technical challenges, economic challenges and societal challenges. Detailed gap analysis for the adoption of V2X in India has been provided in Report 2 of this study.

5.1. Regulatory challenges

One of the significant barriers for V2X implementation in India is the lack of well-defined standards and regulations. These include grid interconnection regulations for V2X resources and standards for V2X charging. Without these regulations, the V2X resources cannot participate in the grid support services. In addition to these, there is also the need of energy market regulations that enables small providers in participating in the energy market products. Further, for use of V2X in distribution network support services such as congestion management, local reactive power support, voltage support, there needs to be a system in place that enables the V2X resource to participate in these services. Adequate tariffs need to be in place as well as local markets that can be used to access these products.

5.2. Technical challenges

One of the major challenges in the development of V2X products and services is the limited number of EVs and EVSE with V2X capability. In the Indian market as of 2022, there are no EVs or EVSE that are capable of bidirectional charging. The EV ecosystem's various stakeholders would also need a robust communication infrastructure with regulated and open communication protocols. Aside from communication standards, the details of data that must be exchanged between different entities in the EV stakeholder chain must also be specified. The infrastructure needed to host Demand Response programs is still lacking in most DISCOMs in India. This is another critical challenge in V2X application as due to inexperience of the DISCOMs in these, prior pilot studies on DR may be needed. Depending on the requirement of the demand response program or the grid support service, some V2X applications necessitate additional hardware and software such as energy management system (EMS), smart meter installation, smart loads etc. which is a combination of hardware and software components that work together to efficiently manage the energy usage of homes/buildings. Also unlike stationary battery storage, where the capacity available is always known, the stochasticity in charging behaviour of

EVs mean that, the aggregated capacity of storage available from EVs at any point of time is variable. This makes it difficult for aggregators to estimate the amount of capacity available from EVs to participate in the different V2X services.

5.3. Economic challenges

The high cost of bidirectional chargers is currently one of the major prohibitive factors in implementation of V2X services[12]. The high capital investment in the installation of bidirectional chargers decreases the potential profit that can be made by participating in the different V2X services. Further, energy storage devices, which can be considered both as producers and consumer of electricity, are taxed both during consumption and generation of electricity, which again reduces the profit margin for the energy storage operator.

5.4. Societal challenges

In addition to the other challenges mentioned above, the perceptions of the EV users is another critical issue on V2X adoption. If not optimally controlled the EV battery may be significantly drained rendering it unable to be used for transportation services which is one of the primary concerns of the EV users. The EV users are still not educated about V2X, its applications and potential benefits. The lack of knowledge about V2X makes the users skeptical to adopt the technology. Also there has always been a historical distrust between consumers and grid operators which can reduce the cooperation needed between the two entities for the successful implementation of V2X.

The different challenges and barriers for V2X implementation have been summarized in Table 9.

[12] AC bidirectional chargers are considerably cheaper compared to DC bidirectional chargers, which would address the economic challenges to a large extent. Renault has recently released their AC V2G solution to be used in Renault 5, to be launched in 2024.

Table 9: Challenges and barriers for V2X implementation

Regulatory Challenges	Technical Challenges	Economic Challenges	Societal Challenges
Grid Code Regulations	Limited V2X market	High cost of bidirectional chargers	Reduced vehicle availability for transportation purposes
Standards for bidirectional charging/discharging and communication protocols	Communication complexity	Double taxation	EV user's interest
Technical discrimination from providing grid support services	Limited experience with demand response programs	Lack of financing options	Historical distrust between grid operator and consumers
Enabling small providers to participate in TSO market	Bid structure		
Establishments of tariffs, markets, auctions at DSO level	Distance to reservation		
Standardization of contracts	Battery degradation		
	Stochasticity in charging behaviour		
	Ancillary product symmetry		
	Stochasticity in EV charging location		
	DER management		
	Requirement of supporting infrastructure		
	Forecasting of EV charging load		

6. Enabling V2X in India

With the world moving toward eMobility, V2X presents a unique opportunity for India. From the techno-economic analysis it has been determined that V2X can provide a wide array of benefits to the grid operator, the EV users and the EV ecosystem as a whole. The transition towards electrification of transportation would require increased cooperation between the electrical sector and the transportation sector. While historically transportation and electricity were distinct mutually independent sectors, the emergence of electric vehicles have led to increased coupling between the two. This sector coupling is epitomized by V2G as electricity, remunerations and responsibilities flow in both directions between the EV and the grid. This sector coupling can also profoundly impact and reshape the conceptions of the people on the utility of a vehicle.

Depending on the V2X application, there are multiple requirements to enable V2X in India. Besides V2X capable hardware requirements, the necessary regulations, standards and policies are the major enablers of V2X. These include connectivity regulations, safety regulations, energy market products availability as well policies to increase the attractiveness of V2X applications. The framework to enable V2G in India is shown in Figure 6:1

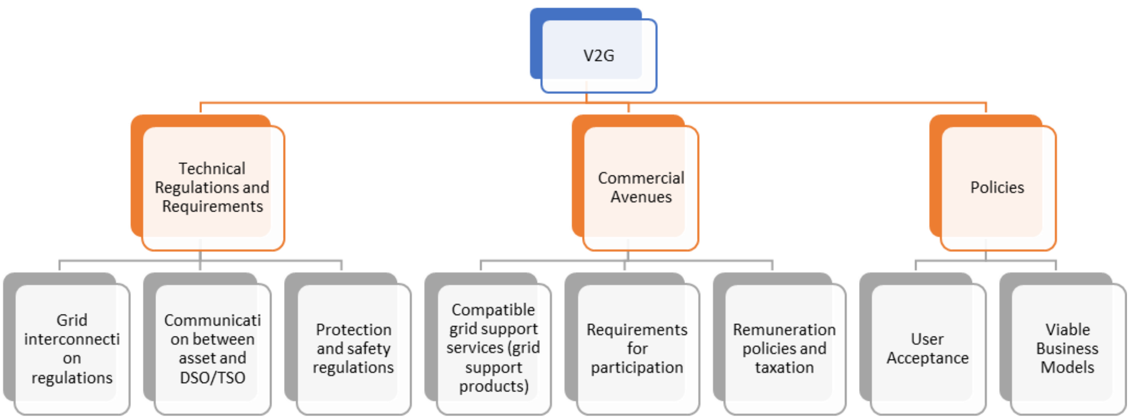

Figure 6:1: Requirements for V2G

The following steps would go a long way in the implementation of V2X in India.

1. **Research on V2X:** This includes creation of V2X specific labs and inculcate V2X education in the EV courses provided in the different universities across the country. Collaboration with international universities and stakeholders could provide the learnings from the substantial body of research, development, trials,

and first deployments across the world and would enable India to leap-frog ahead and become a leader in V2G.

2. **V2X trials:** In addition to desktop research, there is need of pilot projects on V2X to identify the unique characteristics of V2X in an Indian context. E-mobility industry player, grid operators and academia need to come together and design pilot projects on the different aspects of V2X. these projects should also include the support from the regulators and the government, so that the necessary policies and regulations can be designed based on the learnings from the pilot projects.
3. **Need of adequate hardware and software:** In the current EV ecosystem in India there are no available V2X capable hardware. The primary reason for this is the lack of demand which makes OEMs unwilling to provide hardware for a market which has not developed yet. To enable V2X, there is need for hardware capable of V2X applications. These include V2X capable chargers, EVs, metering infrastructure as well the grid infrastructure. Development of software packages and interoperable community protocols are also equally important in the implementation of V2X in India.
4. **Need for adequate regulations:** Regulations can prove to be one of the key bottlenecks when it comes to V2X implementation. While EVs are technically capable of the different V2X capabilities, without the necessary regulations they would not be able to participate in the respective services. So, there is an urgent need of adequate regulations to unlock V2X.
5. **Adequate Policies: L**ooking at the nascent stage of V2X in the country the role of policies is to start the V2X ecosystem in the country. This would require making V2X commercially viable as well increasing the awareness of the public regarding V2X and its applications. The EV users are still not educated about V2X, its applications and potential benefits.
6. **Favourable tariffs:** The regulations would help in removing the barriers for V2X integration from a technical viewpoint. However, for widespread proliferation of V2X , there needs to be presence of commercial avenues that can make V2X commercially viable. Here, the role of tariffs is crucial in enabling V2X. These tariffs can be time-based tariffs where the price of energy is pre-determined based on the time of day, or they can be dynamic tariffs based on the generation and load levels in the network.

Action plan for V2X implementation in India

Information/Education
What is V2X?

Webinar for Government

Participants
- Government
- Regulators
- Grid Operators

Webinar for Industry

Participants:
- Industry
- Automobile
- Infrastructure
- Software

Study tours California, Denmark, UK for regulators & policy makers

Dissemination
Spread the news

Extensive awareness campaigns

- LinkedIn
- News papers
- TV
- Conferences
- Professional papers
- YouTube

Establish National V2X Labs

Establish V2X Lab at technical universities and research institutes

Establish V2X Lab at ITI and Polytechnic institutes

- For students
- For show case
- For testing
- Developing V2X workforce

V2X Projects
Show case projects

V2G Projects

V2H Project

V2B Project

- AC V2X
- MHDV
- Reactive power services
- Integration with PV
- Emergency services (V2H/V2B)

Establish standing work groups

Interconnection Work group

Standards

Form Industry Associations Work groups

- CharIn
- Vehicle Grid Integration Council (VGIC)
- Open Charge Alliance (OCA)

Annexure

V2G Field Trials by IIT Bombay

To extend the findings of this study, Grid Integration Lab IIT Bombay has undertaken two field pilot studies to demonstrate various V2X applications, with primary focus on V2G, V2H and V2V applications. The first pilot is primarily focussed on V2G, V2H applications, while the second pilot is focussed on Renewable Energy based V2G and V2V demonstration in a public charging station. These two field pilots are expected to demonstrate V2X technology and its capability along with finding challenges in implementation of V2G in Indian EV ecosystem. Dissemination events on the findings of V2G field trials are planned to be conducted next year. To stay tuned about the progress of the V2G field trials, interested persons may visit 'V2G Field Trials' tab of [Grid Integration Lab IIT Bombay]() website.

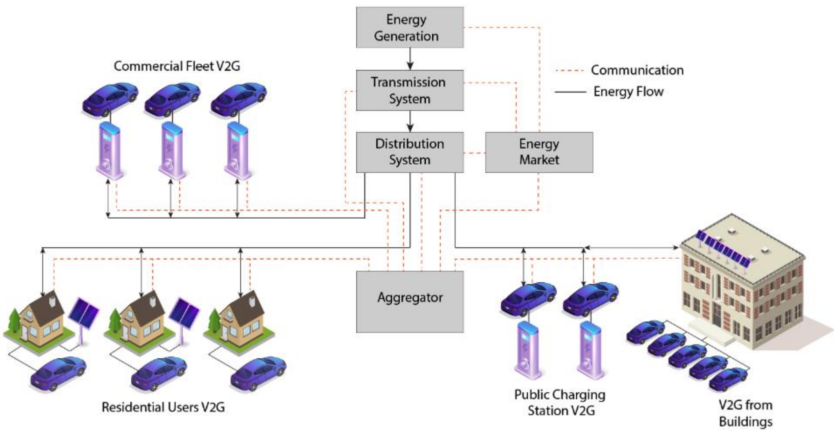

Figure A:1. V2G system architecture

Figure A:2. V2H system[13]

[13] Gaton, Bryce, "We're building a new house. What do we need for bidirectional EV charging?", The Driven, May 13, 2019. https://thedriven.io/2019/05/13/were-building-a-new-house-what-do-we-need-for-bidirectional-ev-charging/

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