GRID INTEGRATION LABORATORY
IIT BOMBAY

In cooperation with
Government of India
Ministry of Power
Central Electricity Authority

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

Report 2

TECHNO-ECONOMIC ANALYSIS AND RECOMMENDATIONS FOR V2X IMPLEMENTATION IN INDIA

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

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Authors

Prof. Zakir H. Rather (IIT Bombay)
Mr. Angshu Plavan Nath (IIT Bombay)
Mr. Pratosh Patankar (IIT Bombay)
Mr. Desu Venkata Manikanta (IIT Bombay)

Contributors

Shri Ashok Kumar Rajput (CEA)
Ms. Purvi Chandrakar (IIT Bombay)
Ms. Ruchi Kushwaha (IIT Bombay)
Next Dimension, California

Reviewers

Mr. Bjoern Christensen (Next Dimension)
Grid Integration Lab Team (IIT Bombay)

Designed by

Ms. Ruchi Kushwaha (IIT Bombay)

Contacts

Prof. Zakir H. Rather (IIT Bombay)
zakir.rather@iitb.ac.in
Mr. Angshu Plavan Nath (IIT Bombay)
194170008@iitb.ac.in
Ms. Ruchi Kushwaha (IIT Bombay)
22d0646@iitb.ac.in

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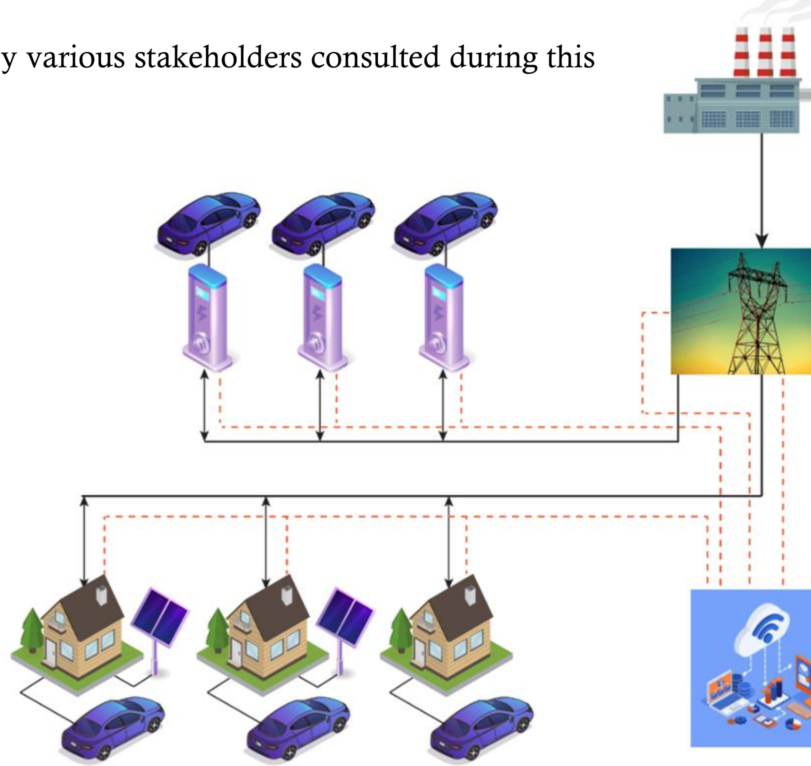

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अध्यक्ष तथा पदेन सचिव भारत सरकार
GHANSHYAM PRASAD
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सत्यमेव जयते

केन्द्रीय विद्युत प्राधिकरण
भारत सरकार
विद्युत मंत्रालय
सेवा भवन, आर.के. पुरम
नई दिल्ली–110066
Central Electricity Authority
Ministry of Power
Sewa Bhawan, R. K. Puram
New Delhi-110066

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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)

दूरभाष / Telephone : 011-26732201, 26732222, ईमेल / Email : chair@nic.in, वेबसाईट / Website : www.cea.nic.in

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.

Willett Kempton

Prof. Willett Kempton

सत्यमेव जयते

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Indu Shekhar Jha
Member

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)

तीसरी मंजिल, चन्द्रलोक बिल्डिंग, 36, जनपथ, नई दिल्ली-110 001
3rd Floor, Chanderlok Building, 36, Janpath, New Delhi-110 001
Phone : 91-11-2375 3912 Fax : 91-11-2375 3923, E-mail : isjha@cercind.gov.in

Alok Tandon
Chairperson

सत्यमेव जयते

JOINT ELECTRICITY REGULATORY COMMISSION
(For the State of Goa and Union Territories)
3rd& 4th Floor, Plot No. 55-56, Phase IV, Udyog Vihar,
Sector 18, Gurugram-122015.
E-mail: chairman.jercuts@gov.in

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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List of Abbreviations

2W	2-wheeler
3W	3-wheeler
4W	4-wheeler
ACC	Annualized capital cost
ACN	Adaptive Charging Networks
ALCC	Annualized life cycle cost
BEV	Battery electric vehicle
CUF	Capacity Utilization Factor
DC	Direct Current
DCFC	DC fast chargers
DISCOM	Distribution Company
eMARC	Monitoring and Analysis of Residential Electricity Consumption
EV	Electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles
ICE	Internal combustion engine
IEX	Indian Energy Exchange
INR	Indian National Rupee
LV	Low voltage
p.u.	Per unit
PAR	Peak to average ratio
PCC	Point of Common Connection
PCS	Public charging station
PG&E	Pacific Gas and Electric Company
PHEV	Plug-in hybrid electric vehicle
RE	Renewable Energy
SoC	State of charge
ToD	Time-of-Day
TOD	Time-of-day
TOU	Time-of-use
V1G	Unidirectional smart charging
V2B	Vehicle-to-building
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
V2X	Vehicle-to-everything
VPS	Virtual pricing signal

Chapter 1. Introduction

Climate change is regarded as the "greatest peril contemporary humanity has ever faced," with far-reaching consequences across numerous sectors. In this context, efforts are being made globally to combat this grave issue with the help of new and efficient technologies and sustainable solutions. However, there is ample scope for improvement in this regard. In the recently concluded United Nations Climate Change Conference in Glasgow (COP26), 120 world leaders focused on all aspects of climate change – the science, the solutions, and the political – expressed their will to act against this formidable hurdle. Government of India updated India's Nationally Determined Contribution (NDC) under Paris Agreement in August 2022. As per the revised target, the country plans to increase the installed non-fossil fuel power generation capacity to 50% of the cumulative installed generation capacity by 2030 [1].

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). The governments at both the central and state level, have taken several crucial steps to promote e-mobility. Accordingly, nineteen states have already issued policies to accelerate the growth of EVs as of August 2022. The central government has also launched the second phase of the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles scheme in the same context. The current electric vehicle (EV) ecosystem in India is primarily focused on the unidirectional charging facility. However, there is minimal discussion about using EVs as a resource for grid management by utilizing its bidirectional charging capability.

With the global push towards accelerating the introduction and adoption of EVs, the industry, academia and other relevant stakeholders have begun to view electric vehicles not just as any general load but also as a resource for better grid management and operation. Moreover, EVs with bidirectional capabilites can be used to cater load of a household (V2H), a building (V2B) and other V2X applications. Different studies have

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[1] Government of India, " India's updated first nationally determined contribution under Paris agreement", United Nations Framework Convention on Climate Change, August 2022. https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

estimated that a vehicle, on average, is not being used for almost 95% of the time[2]. By utilizing the underlying storage in such unused vehicles adequately, the stored energy in EV batteries can be used for different support services essential to grid operation. There are multifaceted motivating factors to explore these services. For the grid operator, the added resources would help them to manage the grid better and help in integrating more renewable energy generation; for the EV users, provision of such services would provide monetary benefits and enable them to procure revenue from an otherwise unused asset.

1.1 Structure of the report

This technical report has been split into two separate sections to adequately address the requirements necessary for V2X implementation in India.

- "Section A: Challenges and Way Forward for V2X Implementation in India" highlights the challenges in the current EV ecosystem in India pertaining to V2X integration, which is then followed by an analysis of the different requirements for implementation of the same.
- "Section B: Techno-economic analysis of V2X implementation in India" provides detailed case studies on the impact of EV integration in a real Indian distribution network followed by the different technical and economic benefits that can be extracted from V2X implementation.

The main objective of this report is to educate the Indian stakeholders on the challenges of V2X implementations. Chapter 2 provides the different challenges for V2X implementation in India, which is followed by a brief summary of the various policies and regulations on V2X implemented by different countries around the world in Chapter 3. Chapter 4 highlights the key steps needed for enabling V2X in India, followed by the modifications required in regulations, policies, and technical standards in Chapter 5.

Also, detailed techno-economic analysis supported by a range of technical and cost-benefit case studies have been undertaken to estimate and quantify the potential benefits that can be provided by the V2X applications of EVs have been presented. Chapter 6 analyses the technical impacts of the growing EV demand in an Indian distribution system. In Chapter

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[2] Briones, Adrene, James Francfort, Paul Heitmann, Michael Schey, Steven Schey, and John Smart. "Vehicle-to-grid (V2G) power flow regulations and building codes review by the AVTA." *Idaho National Lab., Idaho Falls, ID, USA* 1 (2012)

7, the potential for EVs to provide reactive power support to the grid has been studied. This is followed by the analysis of frequency support services from EVs, as discussed in Chapter 8. In Chapter 9, the EVs are being used for energy arbitrage, i.e., the EVs are being used to minimize the load to the grid during peak periods and add load to the grid during off-peak periods. The chapter also analyses how EVs can be utilized for increased utilization of renewable energy, which is the need of the hour. In Chapter 10, the capabilities of EVs to support the energy requirements of a local residence/building has been duly explored.

Section A:

Challenges and Way Forward for V2X Implementation in India

Chapter 2. Gap analysis for adoption of V2X in India

The different barriers for implementation of V2X can be categorized into different baskets as given in Table 2.1.

Table 2.1: Challenges and barriers for V2X implementation

Regulatory Challenges	Technical Challenges	Economic Challenges	Societal Challenges	Bureaucratic Challenges	Organisational Challenges
Grid Code Regulations	Limited V2X market	High cost of bidirectional chargers	Reduced vehicle's availability for transportation purposes	Risk aversion	Multistakeholder cooperation
Standards for bidirectional charging/discharging and communication protocols	Communication complexity	Double taxation	EV user's interest	Coordination challenges	Stakeholder value extraction
Technical discrimination from providing grid support services	Limited experience with demand response programs	Lack of financing options	Historical distrust between grid operator and consumers	Lack of systemic analysis prior to policy making	
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				

2.1 Regulatory Challenges

2.1.1 Grid Code Regulations

One of the significant barriers towards implementation of V2X services, is the lack of grid code regulations. These include technical directives specifying the operating limits (voltage and frequency) and response requirements during operating conditions as well as during grid disturbances. Experience with RE integration proves beyond doubt that the relevant grid code regulations, introduced at the right time, has played a key role in the successful integration of RE in most renewable-rich countries. Inspired by the RE integration journey so far, it is therefore important to plan for appropriate grid code regulations so that EVs can be seamlessly adopted into the Indian power grid. Therefore, the design of appropriate grid codes for the use of electric vehicles for grid support services should also be considered.

2.1.1.1 AC vs DC V2G

The difference between AC and DC V2G is only the location of the bidirectional converter. While in DC V2G, the bidirectional converter is in the off-board EVSE, external to the EV, in AC V2G, the bidirectional converter is in the EV itself. While technically there is not much difference, from a regulatory perspective, AC V2G is much more challenging compared to DC V2G. As per grid code regulations, every entity that injects power to the grid has to conform to the grid code regulations and have necessary certifications in place. For DC V2G it implies that each bidirectional EVSE (off-board charger) needs to be certified after rigorous testing. This can be managed as the number of V2G chargers is known to the grid operator. However, for AC V2G, this implies that individual vehicle that is capable of AC V2G needs to be certified if injecting power into the grid, which can prove to be a significant challenge.

2.1.2 Standards for bidirectional charging/discharging and communication protocols

The lack of standards pertaining to the bidirectional charging capability of EVs is another significant deterrent in V2X deployment. Without well defined standards, it is difficult for OEMs to manufacture V2X compatible products. Further, there is also a need for these standards to embrace interoperability to maximize their usability. The charging standards for V2X further also need to consider safety aspects as well, which is one of the critical issues pertaining to V2X.

2.1.3 Technical discrimination from providing grid support services

Although technically V2X is similar to a stationary battery, some market rules prohibit V2X resources by banning aggregation of energy resources in the wholesale market, or when the generation sector is envisioned by the regulators as supply-only resources. Further, this prohibition can also be based on voltage levels at the point of connection or by giving priority to non-aggregated resources[3]. Current market mechanisms are generally designed for the traditional centralized electrical system, and so are hesitant to create mechanisms to account for a more decentralized, renewable energy-based system[4].

2.1.4 Enabling small V2X service providers to participate in TSO market

Under current regulations, small V2X service providers face challenges in participating in the existing reserve market, as for small providers it generally requires a large volume of assets to meet the typical minimum bid capacity. As the number of assets increases, the complexity of coordinating the response of the different assets subsequently increases. Along with the coordinating complexity, the measurement and verification of a large number of small providers also increases the total cost.

2.1.5 Establishments of tariffs, markets, auctions at DSO level

For the use of V2X in distribution network support services such as congestion management, local reactive power support, and voltage support, there needs to be a system in place that enables the Distributed Energy Resources (DER) 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. For example, Piclo Flex is one such type of market in the UK, where

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[3] Thompson, Andrew W., and Yannick Perez. "Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications." Energy Policy 137 (2020): 111136.

[4] Meijer, Wieteke. “A market analysis by the STEPS project: Energy storage – trends and challenges in a rocketing market”. Interreg North-West Europe. https://www.nweurope.eu/media/16803/market-analysis-steps.pdf

the different DERs compete against each other to participate in distribution network support services[5].

2.1.6 Standardization of contracts

To implement V2X services, the roles and responsibilities of stakeholders have to be defined. This also includes drawing up contractual agreements between aggregators and EV users, aggregators and system operators, etc. The absence of guidelines on the same can hinder stakeholders' participation. This necessitates the inclusion of different agreements like standardized contracts with the TSO, DSO, aggregators, and contractors with possible retailers and the consumer.

2.2 Technical Challenges

2.2.1 Limited V2X market

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 that are capable of bidirectional charging. Even in the global market, the number of EVs with V2X capability is significantly low. In the same vein, very few charger OEMs provide EVSEs with V2X functionality. Until V2X capable EV and EVSE models are available, the implementation of V2X would still be a prospect of the distant future.

2.2.2 Communication complexity

To enable V2X, the EV ecosystem's various stakeholders would need a robust communication infrastructure with regulated and open communication protocols. Communication between the aggregator/CPO/eMSP and DSO/TSO/Energy market is required for EV participation in any grid support services such as demand response, ancillary services, and so on. The DISCOM uses communication channels to send signals to the aggregator /CPO/eMSP in order to control the charging powers. In the case of a V2G application that provides critical ancillary services, the system stability would be highly sensitive to the time delay between the grid operator transmitting the command signal and the EV receiving the command signal and acting on it.

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[5] Piclo Flex. https://picloflex.com/

Aside from communication standards, the details of data that must be exchanged between different entities in the EV stakeholder chain need to be specified. For example, what parameters (voltage, power factor, current, etc.) should a CPO communicate to the DISCOM, and what should the data's time resolution be?

2.2.3 Limited experience with Demand Response programs

Although demand response (DR) is available in India in the form of static time based tariffs, most DISCOMs in the India are yet to be experienced with complex DR programs such as dynamic tariff based DR or control based DR. As such, the infrastructure needed to host such DR programs is still lacking in most DISCOMs. This is another critical challenge in V2X application that depicts that due to inexperience of the DISCOMs in these, prior pilot studies on DR may be needed.

2.2.4 Bid structure

Here, bid structure implies the differences in bid size as well as its temporal granularity. The electricity market products vary in their minimum bid requirements. The minimum bid size dictates the number of electric vehicles that are required to be simultaneously operated to provide a service. If the minimum bid size is higher, the number of vehicles required will also increase and will require much more complex coordination of the many entities. Along with the minimum capacity of the bid, the temporal granularity of the bids also plays a significant role. Here, the temporal granularity refers to the length of the product, i.e., how long the resources needs to be engaged in the product when it is participating. The study by Borne et. al studied the impact of temporal granularity on the participation of EVs, where they found that with high temporal granularity, the number of vehicles required to participate in the same product reduces[6].

2.2.5 DER management

The increase in DER penetration possesses many challenges to the utilities, perhaps one of the most influential parameter being the utility feeders' ability to accommodate DERs.

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[6] Borne, Olivier, Yannick Perez, and Marc Petit. "Market integration or bids granularity to enhance flexibility provision by batteries of electric vehicles." Energy Policy 119 (2018): 140-148.

Some of the challenges include overvoltage, phase imbalance, equipment overload, loss of reach or coordination in the protection schemes, and potential harmonic distortions.

Distribution system operators (DSOs) need to act as operating managers of energy distribution networks. DSOs could have access to the distributed flexibilities connected to their grid for the benefit of both the distribution grid and consumers. They need to evolve to take on additional roles such as:

- Peak load management through DERs
- Network congestion management
- Provide reactive power support
- Procure voltage support

2.2.6 Distance to reservation

This parameter specifies how far ahead of delivery, the energy services are purchased, which can be days, weeks, months, or even multi-month periods. Because of the need to predict the behaviour patterns of a mobile resource, V2X Aggregators must be more conservative with the amount of capacity they can provide the further ahead a service is required to be reserved. Markets with shorter procurement durations (hour ahead or real-time) will therefore allow for a more accurate assessment of aggregated capacity and greater involvement from V2X, DERs, and RES alike.

2.2.7 Requirement of supporting infrastructure

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. Without these equipments in place, implementation of V2X services may appear prohibitive.

2.2.8 Battery degradation

Battery degradation is one of the technical barriers for utilization of V2X. With increased usage of battery, the wear and tear of the battery is expected to increase. However, this challenge is not so straightforward. Studies have highlighted that optimal control strategies can be devised that would not only minimize the impact of V2X on battery degradation but may in fact prolong the battery life. This implies that battery degradation could potentially be considered as more of a societal challenge than a technical challenge as educating the general public on this aspect may be difficult as it goes against the traditional norm.

2.2.9 Stochasticity in charging behaviour

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. Further, this stochasticity in charging behaviour is more pronounced for residential EV users, and lesser for commercial fleet operators (as they generally have a fixed schedule).

2.2.10 Forecasting of EV charging load

EV charging load is a new type of load for the distribution system operator. Further, the charging behaviour is highly stochastic as mentioned in Section 2.2.9. The combination of these factors makes it difficult for distribution system operators and aggregators to accurately forecast EV charging load. The uncertainty in forecasting also makes it difficult to aggregators/DSOs/ CMS to schedule EV charging for V2X applications. Implementation of pilots and demonstrations backed by the development of appropriate software / tools for demand – supply forecasting, EV load forecasting, and RE forecasting needs to be adopted.

2.2.11 Ancillary product symmetry

Most ancillary service products have two types of operation, i) *Upward products*, where there needs to be increase in generation or decrease of consumption and ii) *Downward products*, where generation needs to be reduced or consumption needs to be increased. Generally, upward and downward reserves constitute distinct products with different valuations. Although most markets differentiate between these products, some markets do not. In markets in which there is no differentiation between the two product types, only allow for symmetric bids, i.e., the resource has to participate in both upward and downward products equally[7]. However, not all resources can economically participate in both kinds of products. Some resources such as wind, can economically provide downward reserves through curtailment. Imposed product symmetry limits the entry of new resources into the market[8].

2.2.12 Stochasticity in EV charging location

Unlike stationary batteries, aggregated EVs participating in V2X services can be potentially connected at different locations in the distribution network. This necessitates the need for decentralized/centralized charging algorithm that takes into account the location of each individual EV participating in V2X service. Depending on the location where the EV participating in the V2X service is connected to, its net impact on the service takes into consideration the upstream distribution network. An illustrative example is shown in Figure 2:1, which shows that, as different EVs are connected at different points in the distribution network, so the local voltages at the different connection points would be different as well as the net impedance seen by each EV. This would introduce challenges in the coordination of the different distributed EVs in order to provide a cohesive response.

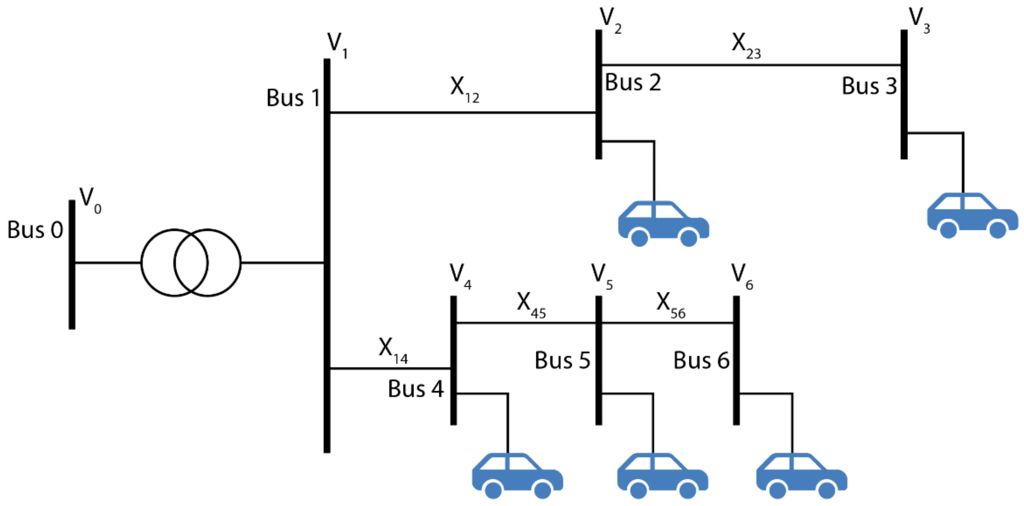

Figure 2:1: Stochasticity in charging locations

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[7] Thompson, Andrew W., and Yannick Perez. "Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications." Energy Policy 137 (2020): 111136.

[8] Thompson, Andrew W. "Economic feasibility of wind energy participation in secondary reserves markets." In Proceedings of the 1st Italian Association of Energy Economics (AIEE) Energy Symposium. Milan. doi: http://www. aieeconference2016milano. eu/pages/programme. html. 2016.

2.3 Economic Challenges

2.3.1 High cost of bidirectional chargers

The high cost of bidirectional chargers is currently one of the major prohibitive factors in the implementation of V2X services. 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.

2.3.2 Double Taxation

Several countries in the world such as Denmark, France, Germany, the UK, the U.S., and the Netherlands employ double taxation for energy storage units. In double taxation, energy storage devices, which can be considered both as producers and consumer of electricity, are taxed both during consumption and generation of electricity. This has a negative impact on the economics of using energy storage and presents itself as a significant barrier for even V2X applications [9].

2.3.3 Lack of financing options

The high investment needed for the implementation of V2X applications may require a significant amount of financing. However, the general non proclivity of financial institutions to finance a non-proven technology may also restrict the growth of V2X technology.

2.4 Societal Challenges

2.4.1 Reduced vehicle's availability for transportation purposes

One of the potential issues with using EVs for V2X purposes is that, if not optimally controlled the EV battery may be significantly drained rendering it unable to be used for transportation services. This is one of the primary concerns of the EV users as highlighted in the V2G trial Project Sciurus, where prior to the start of the trial the lack of charge in

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[9] European Association for Storage of Energy. "Conclusions on EASE Reply to the European Commission Public Consultation on the Revision of the Energy Taxation Directive", November 2020. Energy Taxation Directive (ease-storage.eu)

the car was flagged as one of the critical concerns. Post the trail however, almost none of the participants had the anxiety of the car not being charged[10]. So this implies that the lack of education on the nuances of V2X is a prohibitive factor in V2X application.

2.4.2 EV user's interest

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. This has proven to be one the most crucial barriers of V2X implementation as discovered in numerous surveys and pilot studies[11,12].

2.4.3 Historical distrust between grid operators and consumers

Implementation of V2X services requires cooperation between the grid operators and the general public. However, achieving this may prove to be challenging due to the historical distrust between these entities. This could potentially make EV users hesitant to allow their EV's charging/discharging to be controlled by the grid operators.

2.5 Bureaucratic Challenges

2.5.1 Risk aversion

Despite the considerable decision making power of the policy makers, different factors lead to Indian policy makers to be largely risk averse. In addition to being subject to excessive legal supervision, bureaucrats are frequently subjected to excessive administrative oversight because their decisions are subject to approval and authorization by their superiors. This lack of autonomy deters risk-taking and demotivates risk-free choices alike. Giving bureaucrats the power to make their judgments has a variety of effects on decision-making. The speed and effectiveness of a project's completion are increased by autonomy.

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[10] Cenex. "Project Sciurus Trial Insights: Findings from 300 Domestic V2G Units in 2020"

[11] Kester, Johannes, Gerardo Zarazua de Rubens, Benjamin K. Sovacool, and Lance Noel. "Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study." Transportation Research Part D: Transport and Environment 74 (2019): 277-293.

[12] Noel, Lance, Andrea Papu Carrone, Anders Fjendbo Jensen, Gerardo Zarazua de Rubens, Johannes Kester, and Benjamin K. Sovacool. "Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment." Energy Economics 78 (2019): 525-534.

2.5.2 Coordination challenges

The policy making system in India for EVs involves different ministries as shown in Figure 2:2. The involvement of a higher number of ministries makes it challenging and time consuming for the development of policies.

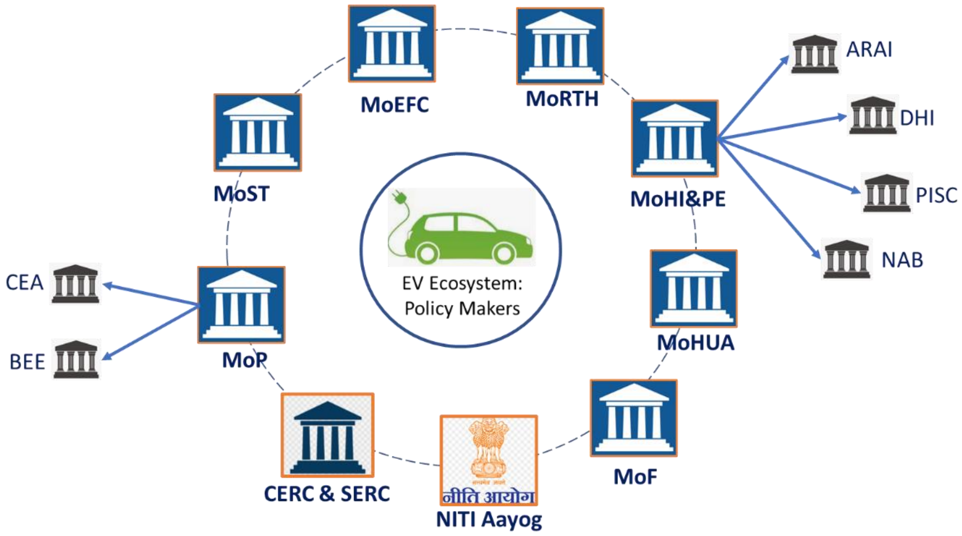

Figure 2:2: Ministries involved in policy making for EV integration[13]

2.5.3 Lack of systemic analysis prior to policy-making

Costs, benefits, trade-offs, and consequences are frequently not adequately analyzed before policy decisions are made. There is a school of thinking that contends that ineffective policymaking and execution are mostly the result of the over-involvement of uninformed generalists. However, experience in government and the private sector reveals that when it comes to the world of policymaking and the making of trade-offs, this is typically best handled by an experienced, well-informed person who has a wide rather than restricted view. Their knowledge of a wide range of related topics, sharp analysis, and judicious use of information supplied by experts to design policy options and weigh their implications are their areas of strength and training[14].

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[13] Zakir Rather, Angshu Nath, Dhanuja Lekshmi, Rangan Banerjee, "Integration of Electric Vehicles Charging Infrastructure with Distribution Grid: Global review, India's Gap: Analysis and Way Forward Electric Vehicle Charging Infrastructure and its Grid Integration in India Status Quo, Critical Analysis and Way Forward", GIZ, 2022.

[14] O.P. Agarwal, T.V. Somanathan, "Public Policy Making In India: Issues and Remedies".

2.6 Organizational Challenges

2.6.1 Multi-stakeholder cooperation

Enabling V2X requires active cooperation between different stakeholders and entities as shown in Figure 2:3. So, coordination between each of the different stakeholders is critical. This makes V2X challenging.

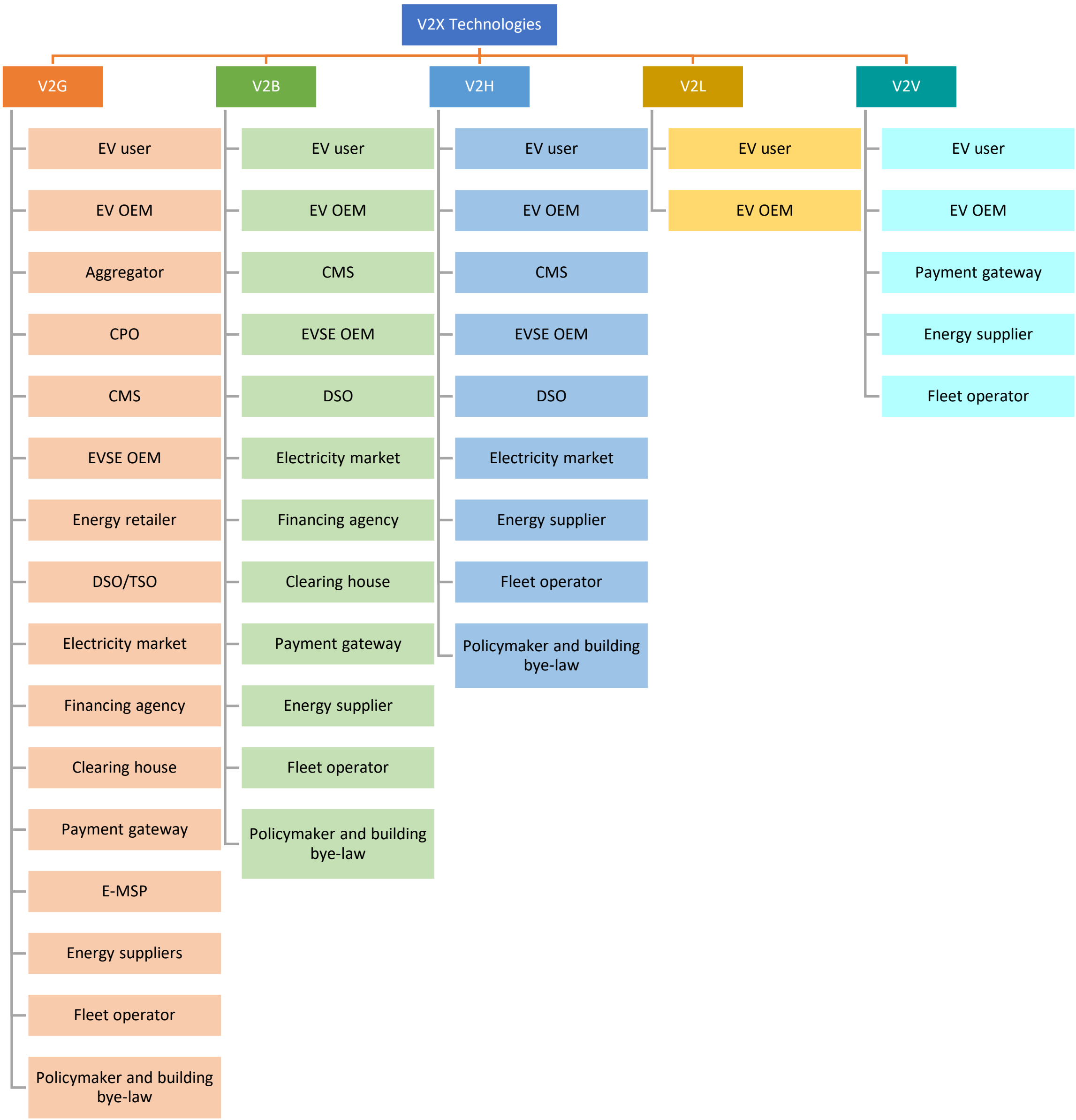

Figure 2:3: Tree-map of stakeholder involvement for different V2X applications

2.6.2 Stakeholder value extraction

In addition to the cooperation between the different stakeholders, the stakeholders need to have an economic incentive to remain interested in V2X . Without adequate revenue generation by the involved entities, they are unlikely to participate in V2X services. This necessitates the creation of unique business models that can help in value extraction for the parties involved. The value creation for different stakeholders involved in V2G are shown in Figure 2:4.

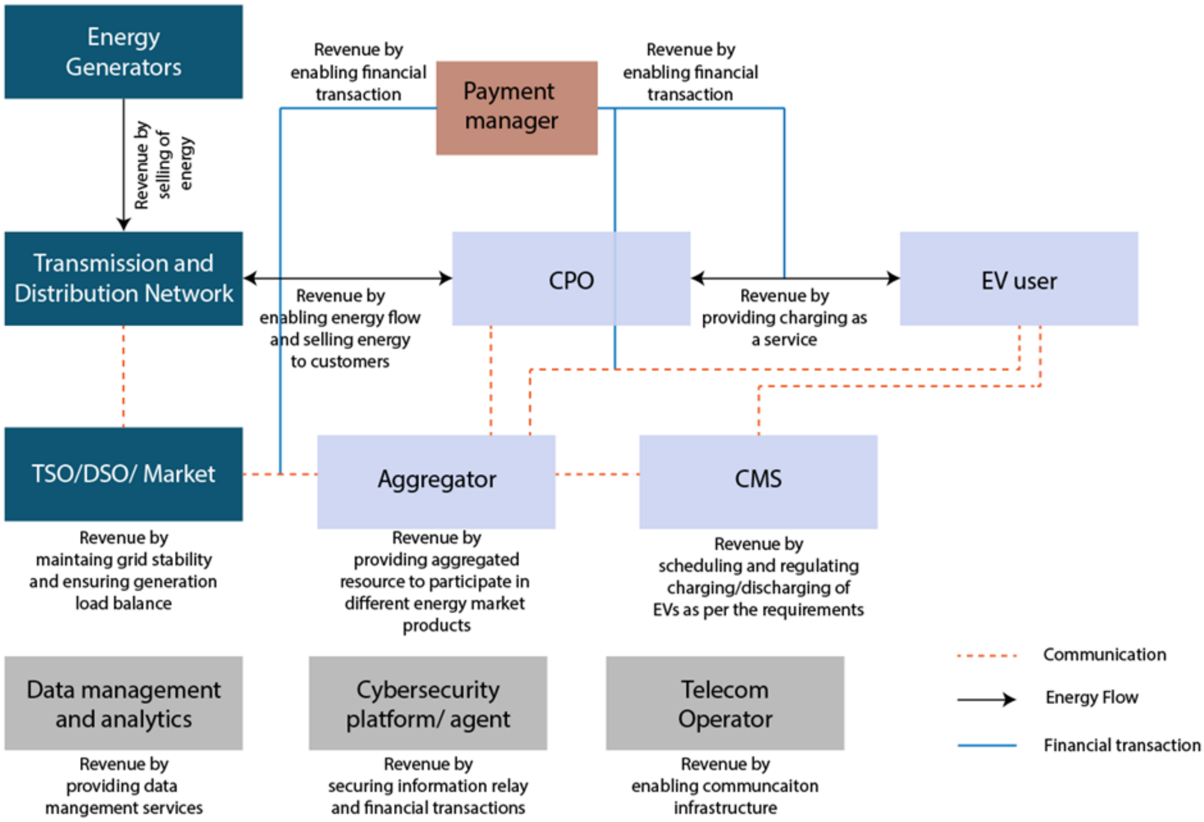

Figure 2:4: Value chain for V2G

Each of the different V2X applications has their own unique set of challenges as summarized in Table 2.2.

Table 2.2: Challenges in adopting V2X services

Barriers	V2H	V2G	V2B	V2L	V2V
Regulatory Challenges					
Grid Code Regulations		☑			
Standards for bidirectional charging/discharging and communication protocols	☑	☑	☑	☑	☑
Technical discrimination from providing grid support services		☑			
Enabling small providers to participate in TSO market		☑			
Establishment of tariffs, markets, auctions at DSO level	☑	☑	☑		
Standardization of contracts					
Technical Challenges					
Limited V2X market	☑	☑	☑		☑
Communication complexity	☑	☑	☑		☑
Limited experience with Demand response programs	☑	☑	☑		
Bid structure		☑			
DER management		☑			
Distance to reservation		☑			
Requirement of supporting infrastructure	☑	☑	☑		☑
Battery degradation	☑	☑	☑	☑	☑
Stochasticity in charging behaviour	☑	☑	☑		
Forecasting of EV charging load	☑	☑	☑		
Ancillary product symmetry		☑			
Stochasticity in EV charging location		☑			
Economic Challenges					
High cost of bidirectional chargers	☑	☑	☑		☑
Double Taxation		☑			
Lack of financing options	☑	☑	☑		☑
Societal Challenges					
Reduced vehicle's availability for transportation purposes	☑	☑	☑	☑	☑
EV user's interest	☑	☑	☑		☑
Historical distrust between grid operators and consumers		☑			
Bureaucratic Challenges					
Risk aversion	☑	☑	☑		

Coordination challenges	☑	☑	☑		
Lack of systemic analysis prior to policy making	☑	☑	☑		
Organizational Challenges					
Multistakeholder cooperation	☑	☑	☑		
Stakeholder value extraction	☑	☑	☑	☑	☑

2.7 Strengths for V2X implementation in India

Despite the challenges and gaps mentioned above, there are several strengths in the Indian ecosystem that can help in the implementation of V2X.

2.7.1 Existing time-based tariffs

Most states in India already have Time of Day (ToD) tariffs for certain sections of it's customer base. Also, a few states have introduced ToD tariffs for EV charging. Such time-based tariff is one of the major requirements for implementation of V2X business models. So, the existence of these tariffs would go a long way in the development of V2X applications for these states.

2.7.2 Electricity market

India already has three energy markets in operation as mentioned below,

- Indian Energy Exchange Limited
- Power Exchange India Limited
- Hindustan Power Exchange Limited

Out of the 196 countries in the world[15], only around 41 countries have operational energy exchanges[16]. This already puts India ahead of 75% of the world's countries. The three energy exchanges provide different products for the concerned stakeholders to participate in. The energy exchanges in accordance with the electricity regulatory authorities in India

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[15] Britannica, T. Editors of Encyclopaedia. "List of countries." Encyclopedia Britannica. https://www.britannica.com/topic/list-of-countries-1993160.

[16] Next Kraftwerke, "List of power & energy exchanges worldwide". https://www.next-kraftwerke.com/knowledge/power-exchanges-list

also have a strong focus on the trading of green energy, as evidenced by the number of products tailored for green energy trading.

2.7.3 National Smart Grid Mission

One of the critical prerequisites for V2G, V2H, and V2B applications is the requirement of smart meters. The Ministry of Power, Government of India has already launched the National Smart Grid Mission through which the process of replacing the legacy energy meters with smart meters have already started. As of December 2022, 52 lakh smart meters have already been installed in the country[17].

2.7.4 Nascent EV ecosystem

The Indian EV ecosystem is still in its nascency. As of October 2022, roughly 0.53% of total vehicles in India are electric vehicles. Accordingly, the charging infrastructure as well it is undergoing development. The nascency of the EV ecosystem provides ample opportunities to the stakeholder and the relevant authorities to design and implement an optimal V2X ecosystem, without the need of reinvesting and redesigning an already existing infrastructure.

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[17] MoP, "National Smart Grid Mission: Smart Metering Status", https://www.nsgm.gov.in/en/sm-stats-all

Chapter 3. Review of International V2X Policies and Regulations

Different countries around the globe have taken steps for the implementation of V2X services and applications. These steps include the roll out of policies and technical regulations that can help in mass market adoption of V2X. In this chapter, these different regulations and policies would be explored.

3.1 Regulations for V2X

3.1.1 Europe

European countries are generally known to be the front runners in sustainable devolvement. A similar story also plays out in V2X, where different European countries have come up with regulations that allow the operation of V2X. According to the expert group consultation conducted by ENTSO-E, the connection network codes at the European level presume that EVs (V1Gs and V2Gs) are covered by the connection network codes but do not need specific handling. A V1G would be considered as a part of the demand (as defined by the Demand Connection Code), whereas a V2G would be considered as part of the generation (codified under Requirement for Generators)[18].

3.1.1.1 Denmark

Denmark was one of the earlier countries to roll out regulations for grid interconnection of V2G entities. The regulations called 'technical regulation 3.3.1 for electrical energy storage facilities' were first introduced in 2017 and then revised in 2019. Through these regulations, the Danish grid operator Energinet has defined 'two-way chargers' (V2G units) as temporarily connected energy storage facilities. This enables V2G units to participate in most services in which stationary storage units are allowed to participate, provided that the V2G units meet the minimum technical requirements[19]. This has led to

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[18] ENTSO-E, "Storage Expert Group: Phase II final report", Belgium, 2020,

[19] Energinet, 'Regulations for Grid Connection'. https://en.energinet.dk/Electricity/Rules-and-Regulations/Regulations-for-grid-connection

one of the earliest commercial operations of V2G, in which EVs are being used for providing frequency regulation services[20].

State	Denmark
Technical regulation 3.3.1 for electrical energy storage facilities	
Enforcement year	2017
Status	Revised in 2019, these regulations define the minimum requirements that a V2X plant needs to possess in order to connect to the Danish Grid.
Impact of implementation	This change in the law allows for the connection of bidirectional chargers and EVs into the Danish grid and participate in different grid support services.

3.1.1.2 United Kingdom

The United Kingdom is one of the leading countries encouraging the adoption of electric vehicles and the vehicle to grid applications. They started an initiative called V2GB (Vehicle to Grid Britain) where the aim of the project is to unlock the understanding of the consumer about vehicle to grid technology, enabling thousands of EV owners to connect with the grid contributing to the UK grid.

In the UK, there are the Engineering Recommendation ***(EREC) G98*** and ***G99*** regulations. EREC G98 includes electricity storage devices as micro-generators and includes electric vehicles operating in vehicle to grid as electricity storage devices but not otherwise with a capacity up to 16A per phase. Units with capacities higher than 16A per phase would need to adhere to the G99 regulations[21].

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[20] Jeff Shepard, ‘First Fully-Commercial Vehicle-to-Grid Hub in Denmark’, 2016. https://eepower.com/news/first-fully-commercial-vehicle-to-grid-hub-in-denmark/#

[21] Energy Networks Association, ‘Connecting generation to the electricity networks’, https://www.energynetworks.org/operating-the-networks/connecting-to-the-networks/connecting-generation-to-the-electricity-networks

State	United Kingdom
G98: Requirements for the connection of Fully Type Tested Micro-generators (up to and including 16 A per phase) in parallel with public Low Voltage Distribution Networks[21].	
Enforcement year	2022
Status	The G98 amendment is completely implemented allowing electric vehicles with current capacities upto and including 16A per phase can be connected to the low voltage distribution network.
Impact of implementation	This change in the law allows more electric vehicles to get connected with the grid and also encourages home owners to buy vehicles-to-home chargers and use their EVs to support their homes during outages[22]

State	United Kingdom
G99: Requirements for the connection of generation equipment in parallel with public distribution networks[21].	
Enforcement year	2022
Status	After the implementation of the G99 amendment, EV owners can now connect their vehicles to the grid / home and send power to the network. This law allows the connection of generation equipment in parallel with the network and sends power back.
Impact of implementation	This law has played a major role in providing support to the pilot projects that are conducted across the UK and now are going to encourage EV owners to buy V2G enabled vehicles.

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[22] Catapault, "V2GB – Vehicle to Grid Britain", https://es.catapult.org.uk/report/vehicle-to-grid-britain/#:~:text=The%20aim%20of%20the%20Vehicle,of%20the%20UK%20energy%20system.

3.1.1.3 Germany

Germany has been at the forefront of renewable energy for more than a decade. They have built a strong network of renewable energy sources like solar plants, rooftop solar, and wind farms. They have also encouraged electric vehicle ownership by passing progressive laws and allowing the integration of electric vehicles for V2G operations as well.

State	Germany
VDE-AR-N-4100, VDE-AR-N-4110, VDE-AR-N-4120, VDE-AR-N-4105: Integration of Low, medium voltage and high voltage power generating sources with the grid.	
Enforcement year	All of them were implemented in the year 2018 - 2019
Status	These laws have been implemented and have been used in developing various applications for electric vehicles and renewable energy sources.
Impact of implementation	The passing of these laws is not only important for electric vehicle owners for V2G operations but also for solar rooftop owners who can now send power back to the grid and earn income.

3.1.1.4 Netherlands

The V2X concept is fast growing in the Netherlands with many start-ups working on vehicle to grid ideas and developing novel solutions. In the Netherlands, the grid operator Tennet also has issued regulations for the integration of V2X resources with the grid. Instead of a separate regulation, the grid code regulations have been incorporated into the electricity grid code itself[23]. There is also the requirement of compliance with the ***NEN-EN 50549-1:2019 regulations***, for parallel operation of generating units with the distribution utility.

The Dutch government has passed laws and made amendments to improve the integration of electric vehicles with the grid allowing better power transfer.

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[23] Elaadnl, 'V2G: the Power Recycling Car'. https://elaad.nl/projecten/v2g-the-power-recycling-car/

State	The Netherlands
NEN-EN 50549-1:2019: Allows the connection of generating plants, intended to operate in parallel with low voltage distribution networks.	
Enforcement year	2019
Status	These laws have been implemented and thus allowing parallel connection to the network building for vehicle to grid operation.
Impact of implementation	These laws have allowed the connection of electric vehicles with and thus can send power to the grid using the V2G standards. This has increased the acceptance of V2G technology in the country and encouraged more users to buy V2G enabled vehicles.

State	The Netherlands
VDE-AR-N-4105: Explains the specifications required for the connection of generating plants with low voltage networks.	
Enforcement year	2019
Status	This law is implemented and has given EV OEM and charger manufacturers specifications in developing V2G enabled vehicles and chargers
Impact of implementation	This law has encouraged EV OEMs and EV manufacturers to build V2G enabled vehicles and chargers that enables the customers to use V2G technology to send power to the grid and V2H as well.

3.1.1.5 United States of America

The United States of America government has been leading the way in introducing V2X for both power transfer and communication between vehicles and other entities. The state governments have brought in laws that encourages the concept of V2X to the general public by looking into the future. California and Delaware have been the frontrunners in enforcing these laws and have encouraged pilot projects and installations of V2G chargers in their states. The USA has also introduced a bill, ***S.508 - A bill to establish a working group on electric vehicles***, which will be establishing the working standards for EV charging infrastructure and the integration of the EV with the grid.

UL 1741: Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources[24]	
Enforcement year	2021
Status	For interconnection of V2G capable devices to the grid, the V2G charger should meet the minimum requirements as specified by this standard.

State	California
Rule 21 of California Public Utilities Commission: Transmission interconnection pathway connection	
Enforcement year	5-11-2021
Status	The state of California has enforced this law allowing the V2G DC operations and a temporary pathway for the interconnection of V2G AC. Rule 21 also requires the communication protocol between the grid operator and the CPO/aggregator/CMS to be in accordance with IEEE 2030.5 protocol.

The Federal Electricity Regulatory Commission (FERC) issued **FERC Order 841** in 2018[25], that expanded the market participation of energy storage resources to include the wholesale market. The order directed the regional grid operators to establish rules to enable the energy storage devices to participate in the capacity, energy, and ancillary

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[24] SCE, “V2G Interconnection Rules” May 2022.

[25] FERC, ‘Electric storage participation in markets operated by regional transmission organizations and independent system operators’, Feb 15, 2018

service markets. This was then followed by the FERC Order 2222. The ***FERC Order No. 2222***, enabled distributed energy resources to participate in the regional organized wholesale markets through aggregation[26]. Electric vehicles have been recognized as one of the distributed resources that can participate in these services[27]. This regulation can be considered as one of the revolutionary regulations in this domain as it presents for the first time a level playing field for DERs with other grid assets in accessing the wholesale energy markets.

3.1.2 Asia

3.1.2.1 South Korea

The South Korean government is keen on improving the reform for the EV markets, especially in the V2G/V2B/V2L segment where companies like Hyundai and KIA have demonstrated V2G capabilities in their vehicles. They have shown the confidence in technology and will be manufacturing more vehicles and charging networks to support the grid.

State	South Korea
The Electricity Business Act & Electricity Utility Act: allows the integration of renewable energy generating sources and battery energy storage systems to connect with the grid to send power.	
Enforcement year	2019
Status	The amendments have been implemented.
Impact of implementation	This amendment has allowed EV OEMs to successfully test V2G operations in their vehicles. Companies like Hyundai and KIA have made successful attempts in developing their vehicles V2G enabled. This has now encouraged V2G charging station installations, thus supporting the grid.

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[26] FERC, ‘ FERC Order No. 2222: A new day for distributed energy resources’, Sept 17, 2020

[27] Federal Energy Regulatory Commission, “FERC Order No. 2222: A New Day for Distributed Energy Resources”, September 2020. https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet

3.1.3 Australia

The Australian Energy Market Operator (AEMO) has created the Distributed Energy Integration Program EV Grid Integration Group to provide a common platform and forum for the collaboration of different industry, regulatory, and government stakeholders on EV activities. To tackle the issues of vehicle-to-grid integration the working group has established a VGO Standards Taskforce. As one of the initial objectives of the taskforce, the definition of VGI includes both unidirectional and bidirectional charging and its capability to coordinate charging, based on external factors[28].

For the interconnection of energy systems to the low-voltage grid via inverters the AS/NZS 4777.2 specifies the minimum requirements. The distribution network operators only allow appliances compliant with the AS/NZS 4777.2 regulation28. As bidirectional chargers inject power into the grid, they are also required to adhere to these regulations however, unidirectional chargers are not covered by this regulation. The specifications covered by the regulation include,

- Harmonic current injection limits
- DC current injection limits
- Volt-watt, volt-var, and volt balance requirements
- Ramping limits
- Anti-islanding protection requirements
- Under and over voltage protection, and under and over frequency protection
- Frequency response requirements
- Disturbance withstand capability including voltage and frequency excursions, voltage phase shift, multiple disturbances and rate of change of frequency deviations.
- Measurement accuracy requirements.

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[28] AEMO, " Distributed Energy Integration Program – Electric Vehicles Grid Integration: Vehicle-Grid Integration Standards Taskforce – Key Findings", May 2021. https://aemo.com.au/-/media/files/stakeholder_consultation/working_groups/der-program/deip-ev/2021/deip-vgi-standards-report.pdf?la=en

AS/NZS 4777.2: Grid connection of energy systems via inverters, Part 2: Inverter requirements	
Enforcement year	2020
Status	Currently active and required for interconnection of energy system to the low voltage grid via inverters[29].

AEMO has also released regulations for the provision of demand response capabilities from smart appliances. The AS/NZS 4755 standard deals with the capabilities of smart appliances for the provision of demand response. A draft version of the AS/NZS 4755 3.4, which related to the provision for demand response from EVs was released for public comment in 2013 but is still awaiting official publication.

AS/NZS 4755 3.4: Operational instructions and connections for charge/discharge controllers for electric vehicles	
Enforcement year	Not published
Status	The draft for public comment on the standard was released in 2013 but has not been published yet[30].

3.2 Comparison of grid interconnection regulations for V2G

As mentioned in Section 3.1, different countries have already published regulations on different aspects of V2G including grid interconnection regulations, tariffs, communication, etc. With V2G acting as a generator in the electrical network, the grid interconnection regulations are of critical importance to ensure the stability and security

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[29] Standards Australia, " Standards Catalogue: AS/NZS 4777.2:2020". https://www.standards.org.au/standards-catalogue/sa-snz/other/el-042/as-slash-nzs--4777-dot-2-colon-2020

[30] Commonwealth of Australia, "Consultation paper: 'Smart' Demand Response Capabilities for Selected Appliances", August 2019. https://www.energyrating.gov.au/sites/default/files/documents/Pooled%20Energy.pdf

of the electrical network. In this regard, investigating the demands of the power system is necessary for setting the parameters (limits, thresholds, times, etc.) of the V2G resources. To avoid impeding the adoption of V2G, requirements must take into account the capabilities of the available generators and the grid conditions in the system. They also need to be future-proof, which necessitates some forecasting of the future power system. In this section, a comparison of the grid connection regulations of V2G resources in the UK, Netherlands, and Denmark has been provided.

3.2.1 Voltage and frequency operating ranges

Most grid codes provide operating ranges for grid-connected entities in the frequency and voltage domain with the aim of preventing unpredictable tripping behaviour during contingencies. Typically, generation resources must be able to operate continuously within specific voltage and frequency ranges and must be connected for at least a specific duration of time within a wider range (to account for temporary disturbances).

Figure 3:1 shows the minimum time duration for which the V2G needs to remain connected to the grid and operate normally as per different grid codes. As can be seen between the frequency ranges of 49 Hz and 51 Hz the V2G unit needs to be operated as normal without any time restriction.

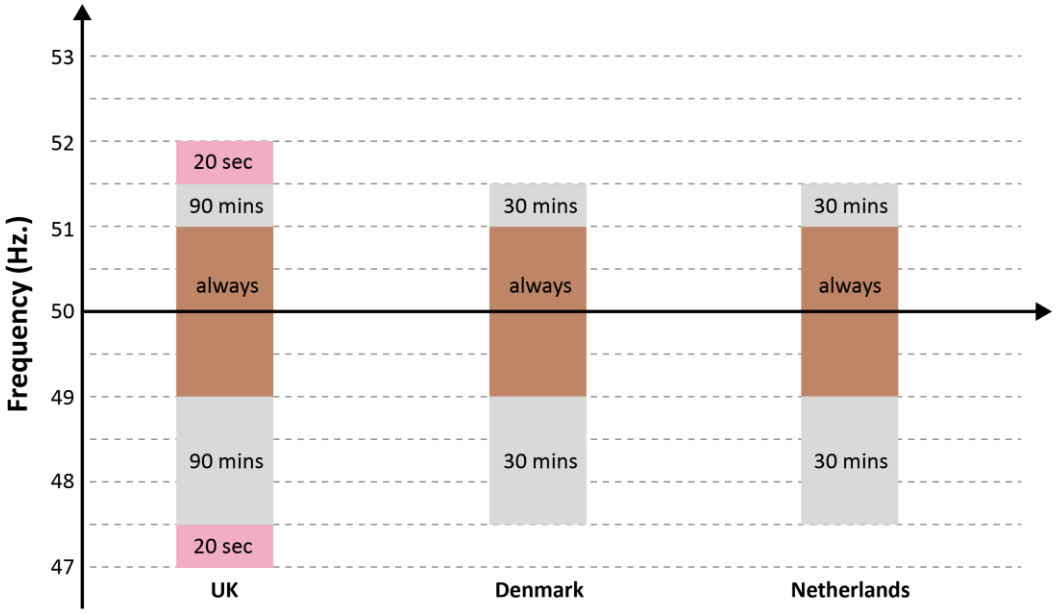

Figure 3:1: Frequency ranges and the minimum time the V2G entity needs to remain connected and operate normally (Source: respective grid codes)

3.2.2 Rate of Change of Frequency (RoCoF) limits

Since the RoCoF is inversely proportional to the quantity of inertia in synchronous systems, it tends to rise as more variable renebwable enenergy, which is based on inverters and does not naturally contribute to inertia, replaces synchronous generation.

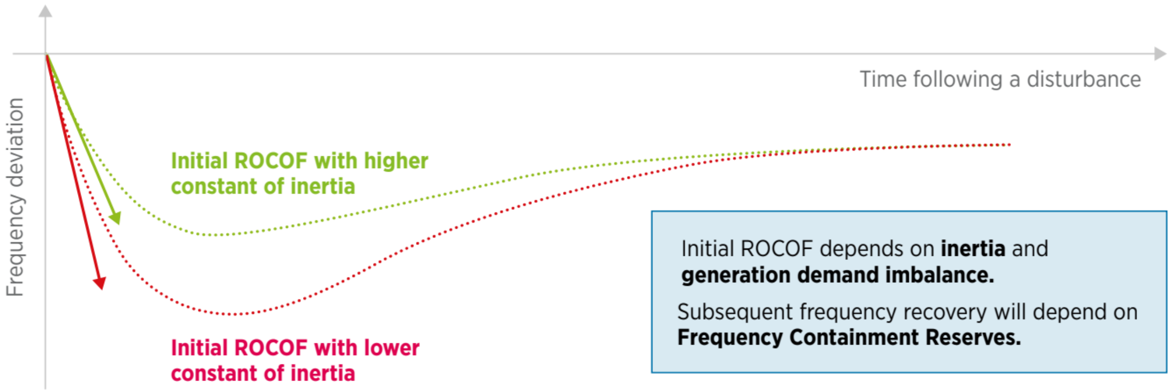

Figure 3:2: Impact of inertia on the RoCoF[31]

However, high RoCoF is undesirable as,

- It reduces the time window for frequency containment reserves to contain the frequency deviation
- It increases the mechanical stress put on the synchronous generators.
- RoCoF is also used in certain anti-islanding protection schemes. So, high RoCoF may lead to the disconnection of DERs.

Based on the individual analysis, the RoCoF limits set by the UK, Denmark, and Netherlands grid code are given in Table 3.1.

Table 3.1: RoCoF limits

	UK	Denmark	Netherlands
RoCoF (Hz/s)	1 Hz/s	2 Hz/s	2Hz/s
Measurement window (ms)	500 ms	200 ms	500 ms

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[31] IRENA, "Grid codes for renewable powered systems", International Renewable Energy Agency, Abu Dhabi. 2022

3.2.3 Frequency control capability requirements

The frequency control capabilities in grid connected entities allow the grid operator to utilize these services and maintain the frequency in the nominal operating range. Depending on the size, capacity, and voltage level at the connection point different frequency control capabilities are mandatory for a grid connected entity to have. The grid codes have also categorized the V2G plants into four types based on the rated power capacities of the plants and the voltage level at the point of connection as shown in Table 3.2.

Table 3.2: Categorisation of V2G plants

		Type A	**Type B**	**Type C**	**Type D**
UK	Power	0.8 kW – 1 MW	1 -10 MW	10-50 MW	>50 MW
	Voltage	<110 kV	<110 kV	<110 kV	>110 kV
Denmark	Power	< 125 kW	125 kW – 3 MW	3 – 25 MW	> 25 MW
	Voltage	< 100 kV	< 100 kV	< 100 kV	>100 kV
Netherlands	Power	0.8 kW – 1 MW	1 – 50 MW	50-60 MW	>60 MW
	Voltage	<110 kW	<110 kW	<110 kW	>110 kW

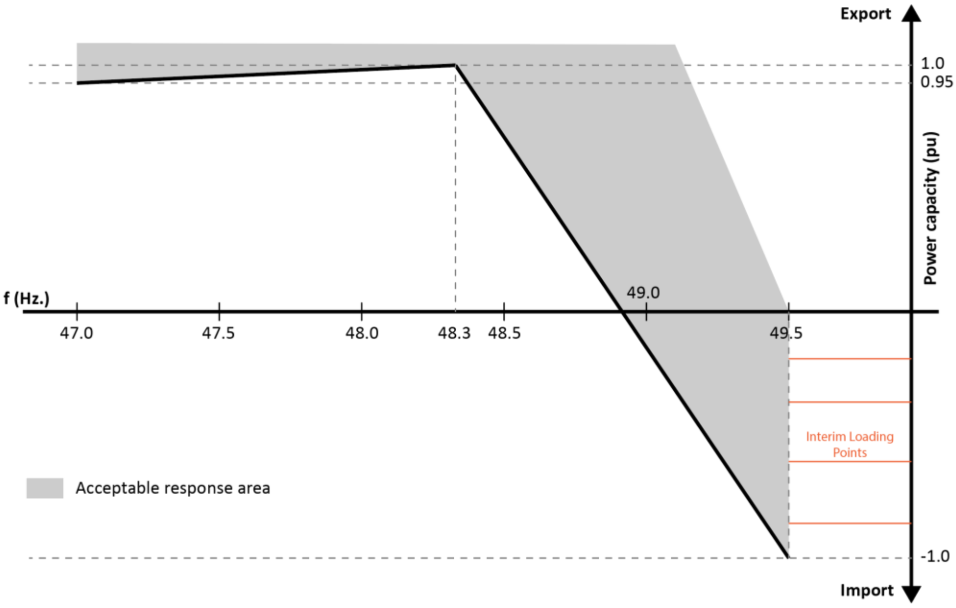
3.2.3.1 Limited frequency sensitive mode

In limited frequency sensitive mode (LFSM), the V2G entities need to respond when the frequency at the point of connection falls outside a certain threshold. Table 3.3 shows for which grid codes and which capacity of V2G capacity, LFSM functionality is mandatory.

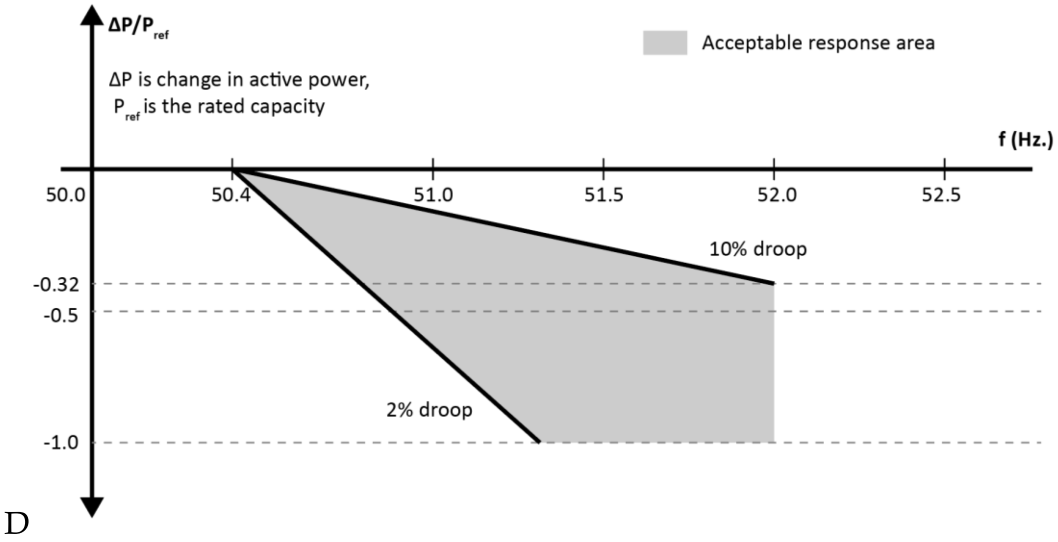
Table 3.3: LFSM requirements

		Type A	Type B	Type C	Type D
UK	Underfrequency	☑	☑	☑	☑
	Over frequency	☑	☑	☑	☑
Denmark	Underfrequency			☑	☑
	Over frequency	☑	☑	☑	☑
Netherlands	Underfrequency	☑	☑	☑	☑
	Over frequency	☑	☑	☑	☑

The LFSM capabilities as per UK grid codes are given in Figure 3:3. Each V2G plant connected to the grid need to have the LFSM capability in the UK. The rate of change of power needs to be minimum at the rate of 2% output per 0.1 Hz deviation of system frequency above 50.4 Hz (i.e. droop of 10%) as shown in Figure 3:3 (b). Similarly, when the frequency drops below 49.5 Hz automatic response should start as per the shaded area shown in Figure 3:3 (a).



(a)



(b)

Figure 3:3: Limited frequency sensitive mode (a) underfrequency and (b) over frequency in UK

The response required in Denmark is shown in Figure 3:4. Here, LFSM – over frequency is mandatory for all plant capacities, but LFSM – underfrequency is only mandatory for Type C and Type D plants. Further, the droop setting for both the upward and downward regulation should be possible to change between 2% and 12%.

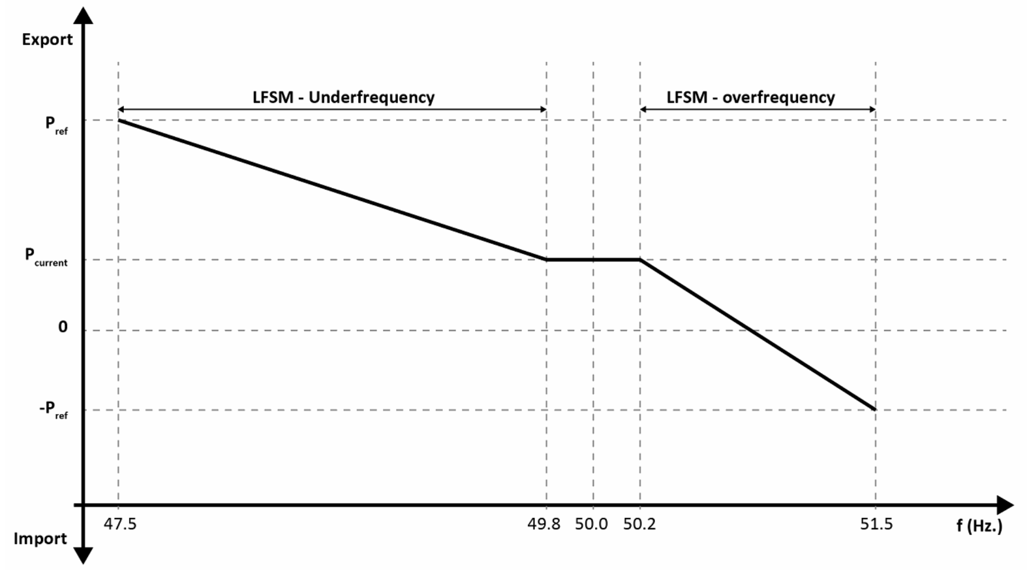


Figure 3:4: Frequency response from V2G plants in Denmark

3.2.3.2 Frequency sensitive mode

In frequency sensitive mode (FSM), the V2G plant needs to provide frequency response under normal operational conditions. Compared to LFSM, FSM is a more demanding control capability, and as such its requirement is only mandatory for Type C and Type D categories of V2G plants in all the three studied regulations as given in Table 3.3. The delivery of FSM response is however based on the contractual agreement between the plant operator and the grid operator.

Table 3.4: LFSM requirements

	Type A	Type B	Type C	Type D
UK			☑	☑
Denmark			☑	☑
Netherlands			☑	☑

The characteristics of the FSM required in UK are given in Figure 3:5. The V2G plant should be fitted with a fast-acting proportional frequency controller to provide the needed response. The droop setting should be controllable between 3% and 5%.

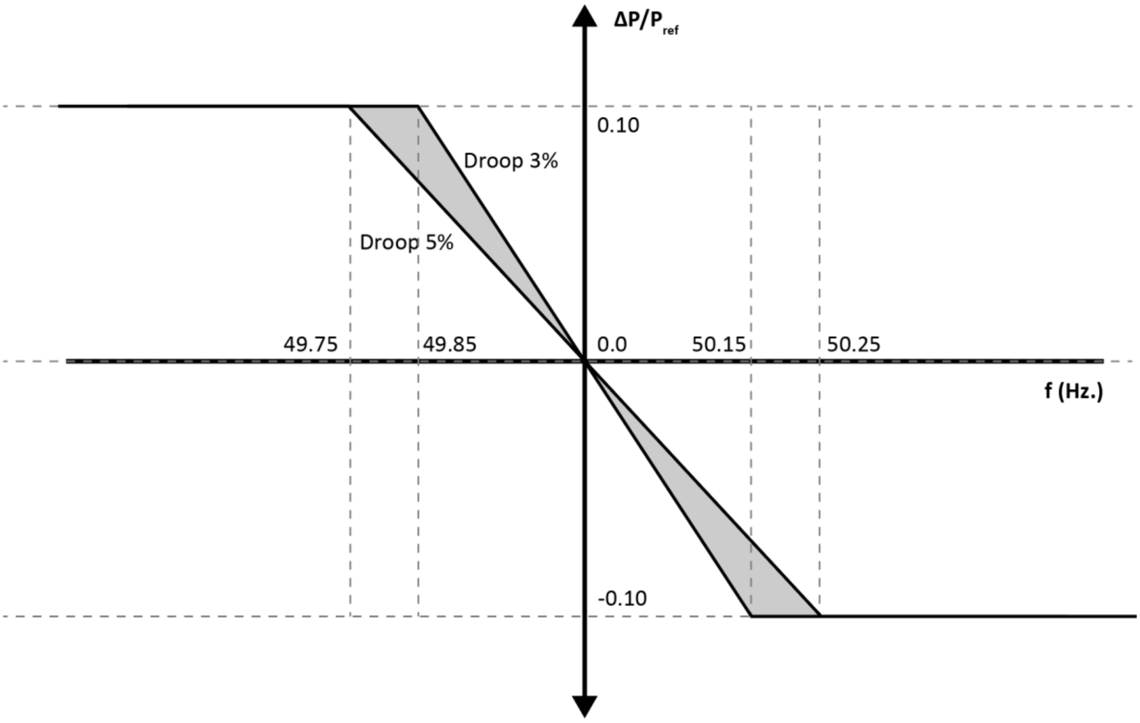


Figure 3:5: Requirement for FSM response in the UK

3.2.4 Fault ride through envelopes

The reaction of the system to a grid fault and the associated requirements of other system components determines the form of FRT envelope, which typically includes requirements for both under- and overvoltage circumstances. The type of failure, the protection plan, and the capacity of the associated generators and loads to stay connected and resume normal operation after a fault, all play a part in this reaction.

Figure 3:6, shows the FRT envelopes for the different V2G capacities and the connection voltages as per the three different grid codes. As can be seen for interconnection with the transmission system, the V2G entities need to withstand voltage drops up to 0 p.u. However, if connected to the distribution system, the FRT regulations are a bit relaxed and the entity needs to withstand voltage drops of up to 0.15 p.u. for Denmark and 0.10 p.u. for the UK. For the Netherlands, the FRT requirements are placed only based on the capacity of the plant.

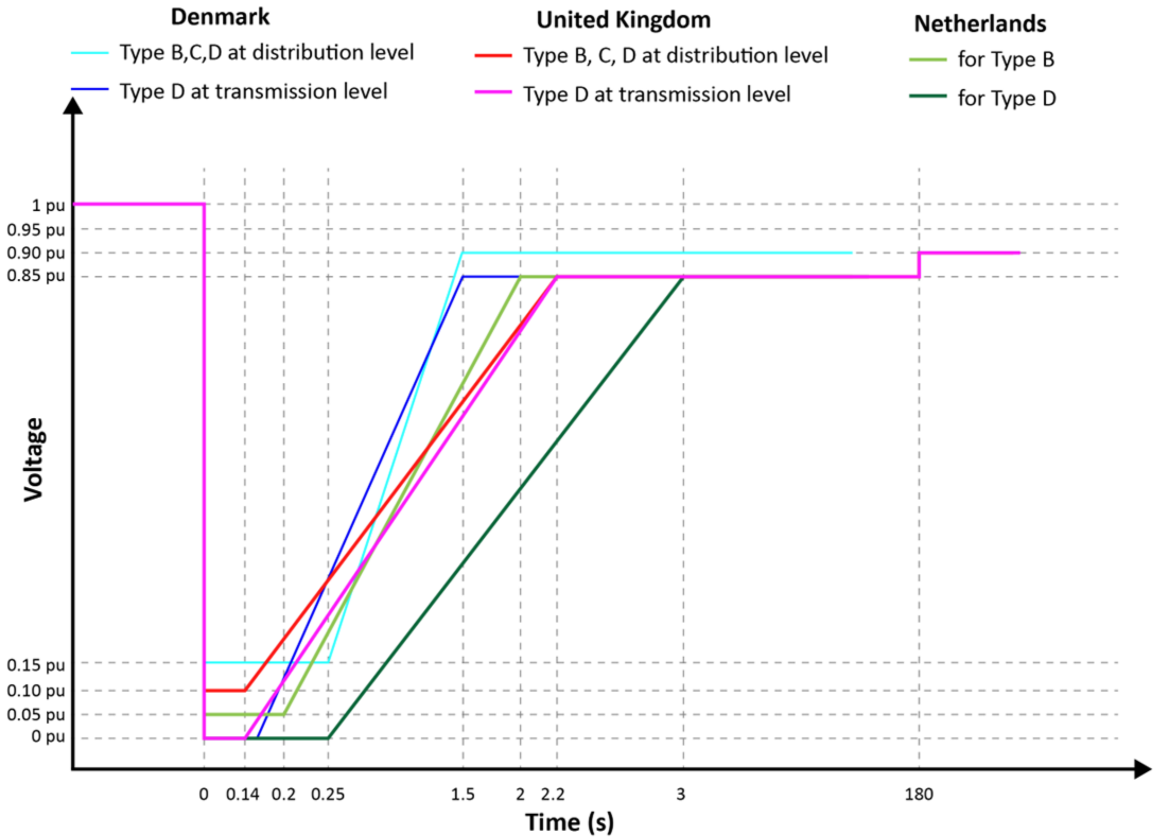


Figure 3:6: Fault ride through envelopes

3.3 Policies for V2X

Regarding policies for V2X, there have been limited developments seen. V2X is still much in the stages of commercial demonstrations and most of the governments are yet to roll out policies for V2X growth. However, there are a few countries that have focussed on V2X development.

3.3.1 United States of America

3.3.1.1 California

The California Public Utility Commission (CPUC) plays a critical role in the transition to zero-emission vehicles (ZEV) in the state of California. As the CPUC also acts as the regulator for California's electric investor owned utilities (IOUs), so it plays a vital role in the grid integration of electric vehicles including tariff design, grid infrastructure development, grid management, and safety. The different bills/ policies and decision orders in the state of California for increased development of V2X is given in Table 3.5.

Table 3.5: Initiatives by the state of California for increased V2X adoption [32]

Policy/ Decision Order/ Bill	**Date of Issuance**	**Description**
Clean Energy and Pollution Reduction Act - SB 350[33]	October 2015	The Clean Energy and Pollution Reduction Act introduced clean energy, air, and greenhouse gas(GHG) reduction goals. As per the bill, it aims to bring down GHG emissions to 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050. One of the aspects of the bill is to increase the zero emission and near zero emission transportation options.
Settlement Agreement Regarding San Diego Gas & Electric Company's Medium-Duty and Heavy-Duty Electric Vehicle Charging Infrastructure Program	August 2019	The order allocated funds for vehicle to grid electric school bus pilot in accordance with the SB 350 act. A total of INR 869 crore (EUR 102 million) to support the installation of charging infrastructure of medium

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[32] California Public Utilities Commission, "Transportation Electrification". https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification

[33] California Energy Commission, "Clean Energy and Pollution Reduction Act - SB 350", https://www.energy.ca.gov/rules-and-regulations/energy-suppliers-reporting/clean-energy-and-pollution-reduction-act-sb-350

and Vehicle to Grid Electric School Bus Application		and heavy duty electric vehicles and funding for a V2G school bus pilot.
SB 676: Transportation electrification: electric vehicles: grid integration	October 2019	The bill requires the Public Utilities Commission (PUC) to establish strategies and quantifiable metrics to maximize the cost-effective and feasible electric vehicle grid integration by January 2030. The bill also describes electric vehicle grid integration as "*any method of altering the time, charging level, or location at which grid-connected electric vehicles charge or discharge, in a manner that optimizes plug-in electric vehicle interaction with the electrical grid and provides net benefits to ratepayers*".
Decision authorizing implementation of optional day ahead real time rate for commercial electric vehicle customers	November 2021	Following the order, Pacific Gas and Electric Company were authorized to provide an optional day-ahead, real-time pricing rate in its business electric vehicle schedules. The energy cost is dependent on the California Independent System Operator's Day-ahead pricing.

3.3.1.2 Delaware

The state of Delaware has released the Senate Bill 12 which facilitates grid interconnection of electric vehicles by including safety standards. This sets the safety requirements for EVs that provide power back to the grid from the batteries.

State	Delaware
Act: Senate Bill 12 (an act to amend title 26 of the Delaware code relating to generating systems with the new society of automotive engineers electric safety standard.)[34]	
Enforcement year	29-05-2019
Status	In the state of Delaware, this act is currently in use and thus encourages more involvement in V2G and V2X installations.

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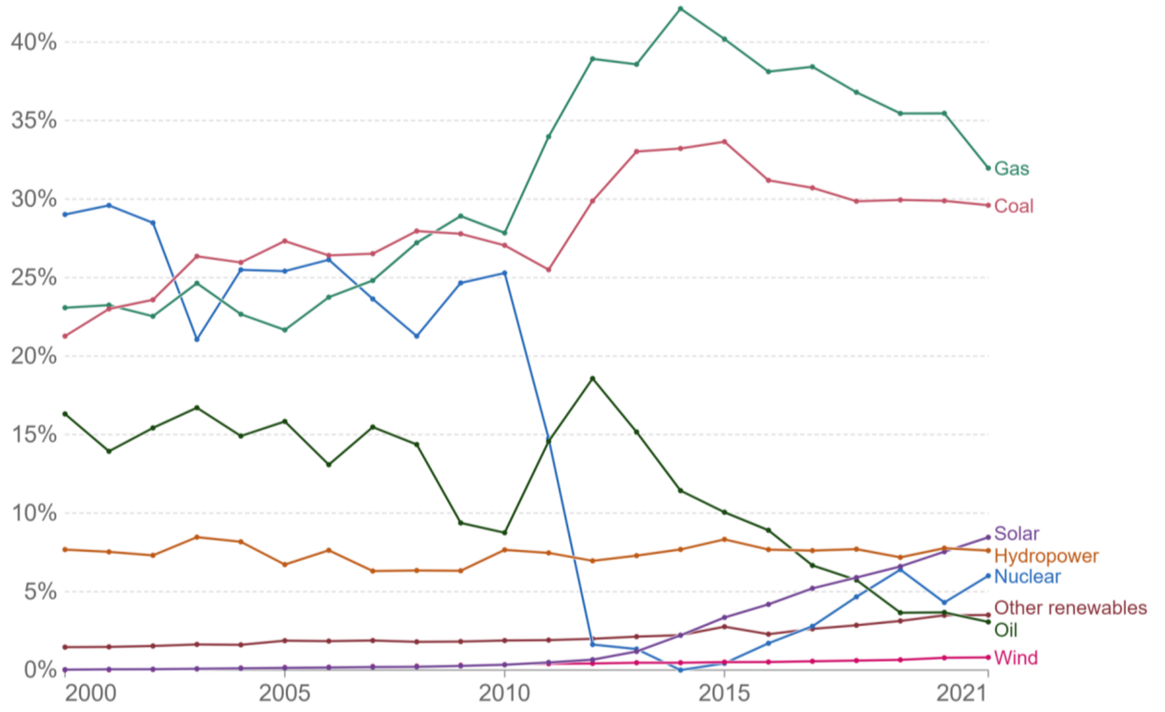
[34] https://legis.delaware.gov/BillDetail?legislationId=37113

3.3.2 Japan

Japan was one of the earliest countries that tried to utilize the potential of V2X in providing flexibility to the grid operators. However, this was fuelled much by the change in the energy policy of the country. Nuclear power was one of the major energy sources in Japan. However, in 2011 a major earthquake led to the Fukushima nuclear disaster, which was the most severe nuclear accident since the Chernobyl disaster in 1986. The events in 2011 significantly changed the energy policies of the country. Following the disaster, there was almost a total suspension of the entire nuclear power plants in the country, which gave rise to increased usage of fossil fuel-based electricity generation as shown in Figure 3:7. But, this led to increased dependency on the import of fossil fuels in the country. The country also promoted energy efficiency and the expansion of renewable energy sector.



Source: Our World in Data based on BP Statistical Review of World Energy & Ember

OurWorldInData.org/energy • CC BY

Figure 3:7: Share of electricity production in Japan[35]

In 2012, Japan launched the Smart House & Building Standardization and Business Study Committee, to put focus on the smart home energy management system, demand response use cases, and communication standards for smart homes. The Agency for Natural

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[35] Ritchie, Hannah and Roser, Max, "Japan: Energy Country Profile", Our World in Data. https://ourworldindata.org/energy/country/japan

Resources and Energy of Japan's Ministry of Economy, Trade and Industry (METI) has developed a strategic plan with a strong emphasis on demand-side interventions[36]. New mechanisms to support the energy transition of the demand side are being developed along with energy efficiency requirements for the industrial sector. In response to the varying energy supply, new frameworks are being implemented to allow large users to be compensated for optimizing their energy usage. In 2020, Japan's TSOs procured a total of 1.3 GW of demand response as reserve power for severe peak hours in their balancing actions, equal to 30% of contracted capacity[37].

The government provides subsidies for the construction of "virtual power plants" (VPPs) that aggregate and remotely operate distributed energy resources at businesses and residences in order to grow the market for demand response (e.g. distributed solar PV, storage batteries, electric vehicles). One of the largest "behind the meter" VPPs in the world was deployed in Japan in 2019[38]. In the first phase, more than 10,000 behind the meter battery storage units were deployed at residential household. Later it would include resources like solar PV, chargers for electric vehicles(including V2G), and smart thermostats for homes.

Japan wants to encourage the reuse of EV batteries for power storage as a way to improve their end-of-life management in preparation of a burgeoning EV market. A lithium battery's capacity may decline after eight to ten years, but it usually still performs well enough to store energy. In a cooperative initiative between Toyota and the convenience store giant 7-Eleven, for instance, discarded EV batteries are being utilized to store energy from solar panels on 7-Eleven stores as a test case. When there is not enough wind to operate the adjacent wind power plant, former EV batteries are used as a backup in Yokohama City37.

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[36] Ishii, Hideo "Japan Demand Response Market Overview", OpenADR Alliance Webinar : OpenADR in Asia Pacific Market. November 7,2019. https://www.openadr.org/assets/20191008%20OpenADR%20Webinar_Ishii_Waseda.pdf

[37] IEA, "Japan 2021: Energy Policy Review", 2021. https://iea.blob.core.windows.net/assets/3470b395-cfdd-44a9-9184-0537cf069c3d/Japan2021_EnergyPolicyReview.pdf

[38] Rezaeimozafar, Mostafa, Rory FD Monaghan, Enda Barrett, and Maeve Duffy. "A review of behind-the-meter energy storage systems in smart grids." Renewable and Sustainable Energy Reviews 164 (2022): 112573.

3.3.3 United Kingdom

Another nation that has put strategic interest in V2X is the UK. While in most other nations, the V2X pilot studies are largely driven by industries and academic institutes, in UK the government itself has put an interest on V2X. The country also has put a significant interest in the grid integration of electric vehicles. In 2021, the country released 'The Electric Vehicles (Smart Charge Points) Regulations 2021'. As the name implies, these regulations mandate the necessary smart charging capabilities in the EV chargers to be sold and operated in the UK, both residential as well as commercial.

As per the UK smart charging regulations, each charge point to be sold in UK post 30th June 2022 must have smart charging functionality. The chargers must be able to send and receive information via a communication network and should be able to regulate the charging speed based on the information received. Also, the chargers need to be preconfigured to have the default charging hours outside the peak load hours. But the owner still retains the right to accept or change the default charging hours. Further, there is also the incorporation of a randomized delay of up to 1800 seconds, such that when responding to a grid signal all the chargers do not respond in synchronism.

Innovate UK, the UK's national innovation agency has also provided funding to multiple different V2X pilot projects. It has funded INR 279 crores (34 million Euro) on 8 different V2G projects and 13 feasibility studies as shown in Figure 3:8. The goal of these projects is to investigate the commercial feasibility of V2G technologies and demonstrate V2G with real UK customers[39].

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[39] Innovate UK, " Innovation in Vehicle-To-Grid (v2G) Systems: Real-World Demonstrators", 2017, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681321/Innovation_in_Vehicle-To-Grid__V2G__Systems_-_Real-World_Demonstrators_-_Competition_Results.pdf

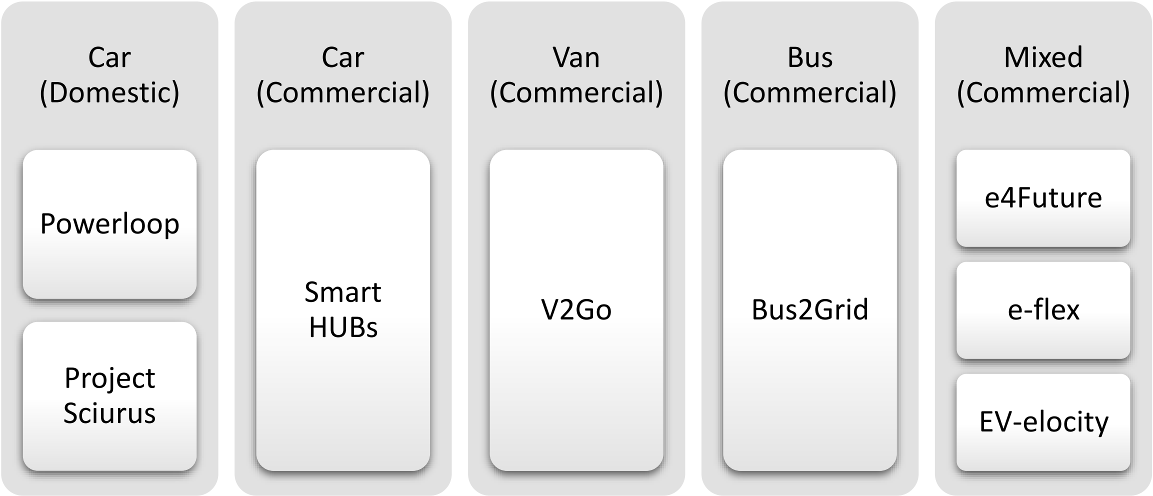

Figure 3:8: Different projects sanctioned by Innovate UK

This has been followed by the 'Vehicle-to-everything (V2X) bidirectional charging Phase 1' funding competition launched in March, 2022. Under this funding competition the Department of Business, Energy and Industrial Strategy (BEIS) would invest a total of INR 114 crores (EUR 13.4 million) on innovative V2X research and projects. The competition aims to unlock the potential of bidirectional EV charging in the provision of flexibility[40].

3.3.3.1 Strategy of the government electricity regulator

The government regulator for electricity and downstream natural gas markets in Great Britain, Ofgem has detailed strategic plan for the growth of V2X in the country. It has identified different priority areas that can help in the growth of EVs and V2X[41].

3.3.3.1.1 Network preparedness for EV adoption

Ofgem has forecasted that to meet future EV charging demands, significant reinforcement of the existing grid infrastructure may be needed. Here one of the challenges is for local network operators to predict where EV uptake is likely to arise. So, Ofgem would be incentivising and funding network operators in order to improve their monitoring and visibility of the low voltage networks. In addition, Ofgem is also encouraging customer-centric modelling to help in better prediction of EV clusters in the network.

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[40] Gov.UK, " Vehicle-to-everything (V2X) bi-directional charging Phase 1: Funding competition", March 2022, Competition overview - Vehicle-to-everything (V2X) bi-directional charging Phase 1 - Innovation Funding Service (apply-for-innovation-funding.service.gov.uk)

[41] Ofgem, "Enabling the transition to electric vehicles: The regulator's priorities for a green, fair future", September 2021. https://www.ofgem.gov.uk/publications/ofgem-ensure-electric-car-revolution-unlocks-full-benefits-consumers

To tackle the issue of network preparedness, Ofgem has incentivized the local network operators to first maximize the flexibility in the network, which includes electric vehicle services. This was assisted by the Network Innovation Allowance and the Electricity Network Innovation Competition which provided the funding for distribution network operators to experiment with new operational, technical, commercial, and contractual arrangement with users in order to maximize the flexibility resources needed.

3.3.3.1.2 System integration of smart charging and V2X

Trials conducted in smart charging has shown substantial shifts in EV charging demand (i.e. provision of flexibility). However, they also felt that there are limited commercial incentives for energy suppliers to provide products and services that incentivize off-peak charging, as the costs incurred by the energy suppliers do not have a significant variation between peak and off-peak periods. To have a more dynamic and cost reflective tariff, in April 2021 Ofgem published the decision to introduce the industry-led implementation of market-wide half-hourly settlement (MHHS). MHHS ensures that the electricity suppliers and retailers are subjected to the true costs of serving their customers, which can further reflect in the development and offering of new tariffs and services. MHHS is expected to save consumers INR 16,059 crore (EUR 1.86 billion) to INR 45,160 crore (EUR 5.22 billion) by 2045[41].

Ofgem is also actively working with the Electric Vehicle Energy Taskforce that comprises of policymakers, regulators, consumer organizations, academicians as well as business organizations across electricity, automotive, and EV charging sectors. The objective of the task force is to ensure that the integration of EVs into the system maximizes the opportunities for both the grid network as well as the EV user and instill confidence among the customers in flexibility provisions from their EVs. To this end Ofgem along with the government has rolled out the following

1. A four-year smart meter policy framework has been fixed to achieve smart meter rollout in the entire country.
2. The government has undertaken active steps for industries to support the uptake of PAS 1878 and PAS 1879 for ‘energy smart’ appliances.

Chapter 4. Enabling V2X in India

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 major enablers of V2X applications are categorized as under.

1. ***Technical Regulations:*** The technical regulations needs to cover different aspects such as the connectivity requirements for interconnection of a V2X capable device with the grid, the protection requirements and the data and communication requirements. The interconnection regulations are one of the pivotal requirements for grid connectivity of any generation resource. These regulations dictate the operation of the resource under normal and abnormal operating conditions as well as the minimum control functionalities that each resource connecting to the grid needs to have[42]. The regulations also needs to cover the protection aspects such as low voltage ride through requirements, high voltage ride through requirements, over and under frequency requirements and so on. Further, the regulations also need to specify the data requirements and the frequency of data transmission

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[42] As per the Danish regulations for interconnection of V2G resources to the grid, based on the rated capacity of the resource, they should have the following control capabilities as mentioned under.

Categories of resources

Category	Rated power
A1	x≤11kW
A2	11Kw <x≤50kW
B	50 Kw<x≤1.5MW
C	1.5MW<x≤25MW
D	25MW<x

Minimum control functionality requirements

	A1	A2	B	C	D
Frequency Response (Over frequency)	Yes	Yes	Yes	Yes	Yes
Frequency response (Under frequency)	-	-	-	Yes	Yes
Frequency control	-	-	-	Yes	Yes
Absolute power limit	Yes	Yes	Yes	Yes	Yes
Ramp rate limit	Yes	Yes	Yes	Yes	Yes
Q Control	Yes	Yes	Yes	Yes	Yes
Power Factor Control	Yes	Yes	Yes	Yes	Yes
Automatic Power Factor Control	Yes	Yes	-	-	-
Voltage Control	-	-	-	Yes	Yes

between the resource and the system operator to enable seamless integration of V2X resources in to the grid.

2. ***Commercial Avenues:*** Commercial avenues are needed to enable the participation of V2X in commercial applications. These can be regulations enabling energy market products where V2G can participate in, or other business models such as increased RE utilization of EV charging, peak shaving products etc. For creation of such products regulated business models needs to be developed. These business models can be created to cater to different requirements such as grid congestion management, increased RE utilization, behind-the-meter optimization etc.
3. ***Favourable schemes and policies:*** The role of policies here is to promote the growth and development of V2X. This can be facilitated through incentivizing the participation of different stakeholders in V2X services. Also, these schemes and policies needs to educate the public about V2X services and ensure their participation in this domain. User acceptance is one of the crucial enablers for unlocking the V2X potential.

4.1 Enabling V2G in India

The framework to enable V2G in India is shown in Figure 4:1. Creation of regulations and an environment to make V2G economically beneficial would help in creating a competitive V2G environment.

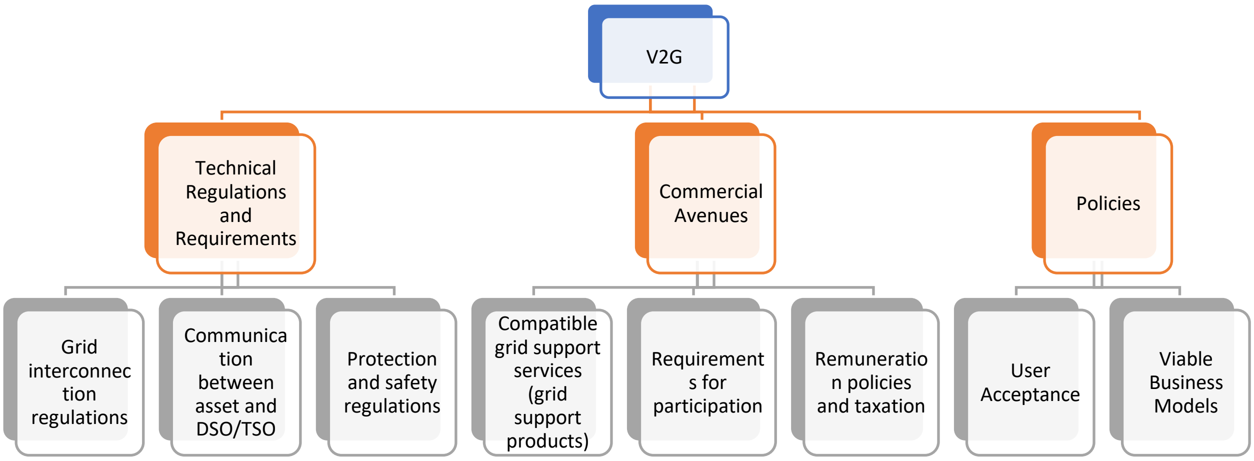

Figure 4:1: Policy and regulatory requirement for V2G

4.1.1 Technical Regulations and Requirements

For the introduction of V2G in the country, adequate technical regulations are necessary including grid connectivity regulations, protection regulations as well as communication requirements.

4.1.1.1 Grid Interconnection Regulations

The regulations define the requirements needed prior to interfacing of distributed generating resources to the Indian Grid. It details on Standards and Codes of Practice for integration of V2G resources into the grid and the requirements of power quality such as Harmonic current injection, voltage flickers etc. A parallel can be drawn here with integration of distributed renewable energy resources in the country. Just as the connectivity regulations for renewable resources helped in the smooth integration of RE in the country, adequate connectivity regulations for EV and V2G can help spur the growth of V2G. However, the current grid connectivity regulations for distributed resources in India have no mention about electric vehicles or V2G. So, here there is need for regulations for interconnection of EV into the transmission or distribution network. Denmark was one of the first countries to come up with interconnection regulations for V2G resources. In UK too, grid interconnection regulations have been developed and is in place. As example grid interconnection regulation of Denmark have been provided in the Annexure.

4.1.1.2 Protection and Safety Regulations

One of the critical aspects for V2G proliferation in the country are the protection and safety regulations. The protection regulations can cater to two different aspects,

- *Protection of the grid point of view:* These regulations would cover the actions required to protect the grid from any malfunction of the resource.
- *Protection from the resource point of view:* These regulations would cover aspects for protection of the V2G resource from any disturbances in the grid.

Further, there needs to be safety regulations to ensure safe and secure operation of V2G. The safety aspects for V2G is specially important as V2G behaves as a energy generation resource. The general safety requirements for V2G applications include aspects such as

- Protection standards to be followed

- Allowable voltages at exposed terminals
- Control over energizing of charging cable
- Earth protection details
- Minimum residual current device (RCD) functionality
- Compliance with standards
- Testing and inspection requirements
- Fire protection requirements

4.1.1.3 Communication Requirements

Another important aspect for enabling V2G is the presence of a robust communication infrastructure. Enabling V2G requires communication of data between different sets of stakeholders as given in Figure 4:2 and Table 4.1. Although most of these communication requirements can be addressed using open-source communication protocols, of critical importance is the communication with the energy utility stakeholders such as communication between *Aggregator / Charge Point Operator (CPO) / CMS and Energy Retailer* and between *Aggregator / CPO / CMS and Operator (TSO / DSO / Market).* Enabling these two communication avenues may require adequate regulations from the relevant central or state electricity regulators.

Table 4.1: Data set requirement for V2G

User and Aggregator	User and Energy Retailer and Grid operator	EV and EV OEM	Electric Vehicle Supply Equipment (EVSE) and OEM	EV and EVSE	EVSE and Aggregator/CPO/ CMS	Aggregator/CPO/ CMS and Energy Retailer	Aggregator/CPO/ CMS and Operator (TSO/DSO/Market)
G_a	**G_b**	**G_c**	**G_d**	**G_e**	**G_f**	**G_g**	**G_h**
Agreement for V2G participation	Energy tariff	Backend support (Troubleshooting)	Backend support (Troubleshooting)	Handshaking and authentication	Handshaking and authentication	Energy tariff (fixed/dynamic)	Connectivity status
Expected plug-out time	Demand Response signals for manual response	Product updates	Product updates	Instantaneous battery terminal voltage	User ID	Billing (Active power, Reactive Power consumption)	Active power at PCC
Location				Maximum rated charging current	Active Power drawn	Forecasted data(optional)	Scheduled Active Power
Added Details about market product				Current SoC	Active power commanded based on response	Time log of energy consumption	Control capabilities (Active power control, reactive power control, power factor control)
Energy consumption during charging session				Charging current requirement from EV	Rated capability	Contracted Demand	Voltage measurement at PCC

Billing				Target charging current	SoC level		Active power current measured in PCC
					Battery capacity		MVAr measured in PCC
					Plug-in time		PF measured at PCC
							Requisite voltage in voltage reference point
							System protection
							Fault incident recording
							Service requirement
							Demand response signal
🟩 Data required less frequently							

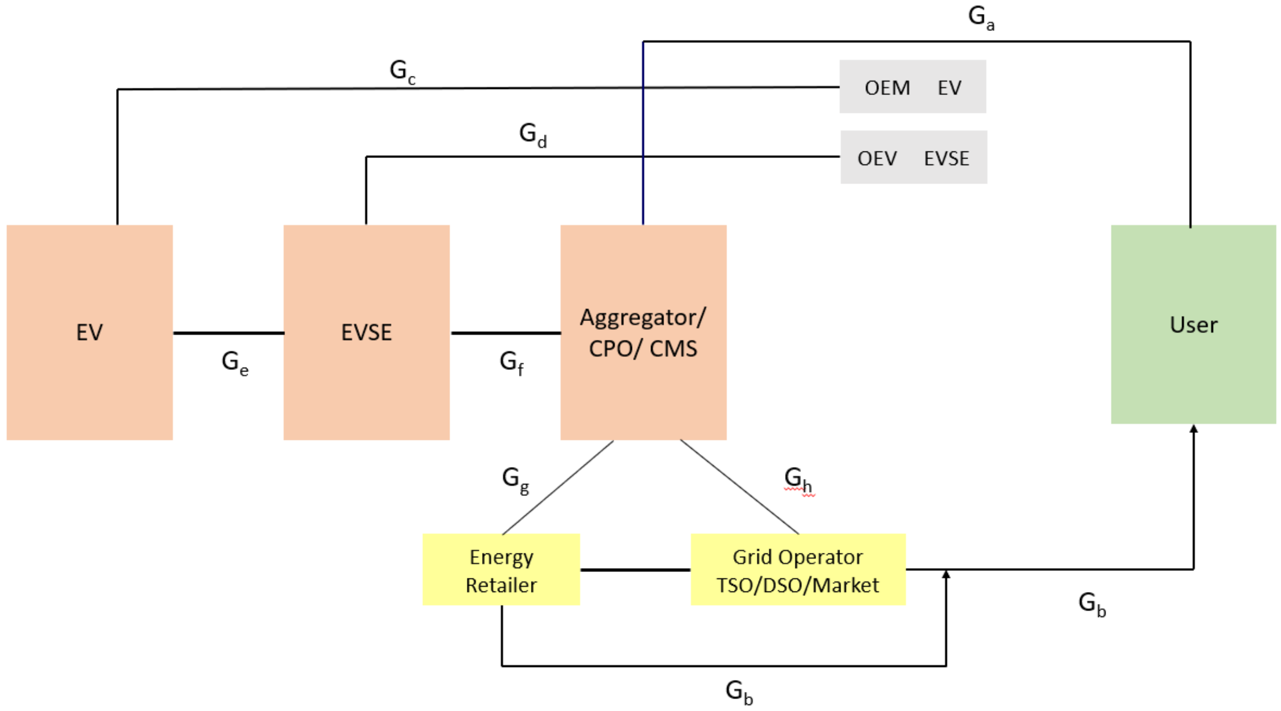

Figure 4:2: Stakeholders involved in V2G and the communication pathways

4.1.1.4 General Network Access

To participate in the energy market products in India, the EV aggregators would need to avail a general network access (GNA) certificate enabling them to access the transmission network. For accessing the short-term market, a temporary GNA is needed. The GNA shall be applied for and provided for a specific capacity and the be granted for a specific period. An applicant shall apply for grant of connectivity for a quantum of its proposed maximum injection to Inter-State Transmission System (ISTS) or proposed maximum drawl from ISTS, whichever is higher. Different individual units can be aggregated to get the GNA. However, the minimum aggregated capacity should be 50 MW, with each individual unit being at least 5 MW. This capacity may present itself as a prohibiting factor for EV aggregators to directly participate in the energy market.

4.1.2 Commercial Avenues

The technical requirements and regulations would help in removing the barriers for V2G integration from a technical viewpoint. However, for widespread proliferation of V2G, there needs to be presence of commercial avenues that can make V2G commercially viable. A meta-analysis was performed by Thompson and Perez[43], where they identified and estimated the value extraction from V2X services. As per their analysis the potential revenue potential across the different value streams have been shown in Figure 4:3.

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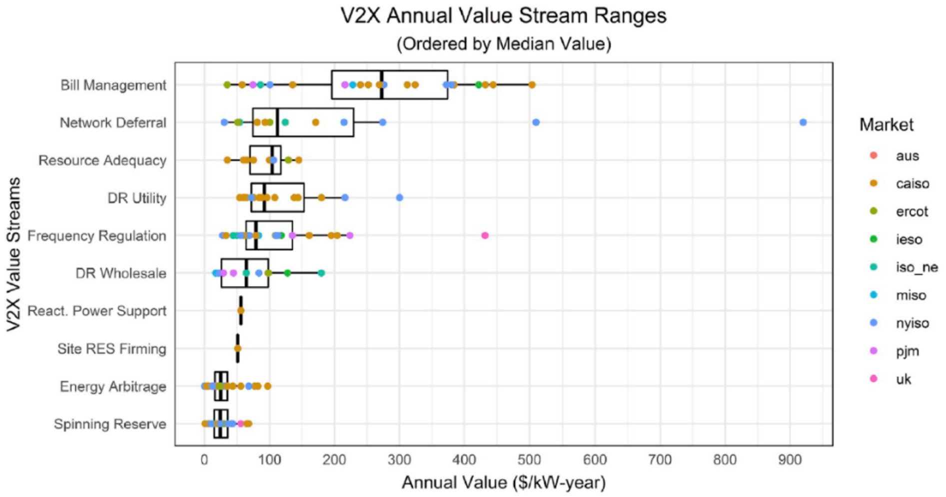

Figure 4:3: Overall economic potential of V2X value streams. The coloured dots show the expected value for different value streams under different electricity market operators and the box plot show the overall range of value that can be extracted from V2X applications[44]

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[43] Thompson, Andrew W., and Yannick Perez. "Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications." Energy Policy 137 (2020): 111136.

[44] ***Bill Management***: Use V2X for reduction of energy and demand charges. Value is added due to cost savings (Applicable for V2B/V2H)

Network Deferral: Use V2X for delaying/reducing the electricity network upgradation requirement in capacity constrained areas (Applicable for V2G/V2B/V2H)

From the figure it can be seen that there is a wide range of estimations of market value of the different revenue streams, which are dependent on different factors such as the local electrical network, the differing market conditions etc. While, some of these value streams can be explored through the energy markets, others may need the presence of markets in the distribution sector as well. For example, resource adequacy, DR wholesale, ancillary services such as frequency support, black start support etc. would require the participation of EVs in the energy market of the region. However, other value streams such as congestion management, DR utility, reactive power support, energy arbitrage etc. may require a market like structure in the distribution sector as well.

4.1.2.1 Favourable tariff regulations

Some of the most valuable V2G value stream are the bill management of the customer, energy arbitrage and behind-the-meter optimization. For unlocking these value streams there is need of time based tariffs. 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.

Most Indian states have implemented specialised EV prices, however only a few of those tariffs incorporate a ToU plan for EV charging. ToU rates can help with grid congestion management and are one of the simplest ways to enable smart charging, hence it is strongly advised that ToU schemes be included for EV charging.

The prevalent tariff structures in the few of the major European countries are shown in Figure 4:4. From the figure, most of the utilities in Norway have opted for dynamic energy tariffs. The 100% roll-out of smart meters in Norway is one of the major reasons for successfully implement dynamic tariffs. While utilities in other countries such as

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Resource Adequacy: Provide power by discharging of EVs in order to reduce demand, and helping maintain generation-load balance at all periods (Applicable for V2G)
DR Utility: Provide demand response services in response to distribution grid operator signals.
Frequency Regulation: Provide support in maintaining system frequency by participating in frequency regulation services (Applicable for V2G)
DR Wholesale: Provide demand response services in response to electricity market operator signals.
Reactive Power Support: Adjust reactive power provided by EVs and charging stations in response to voltage deviations as recommended by the system operator. (Applicable for V2G)
Site RES Firming: Control EV charging/discharging to firm solar/ wind or other renewable generation resources to improve renewable energy utilization. (Applicable for V2G/V2B/V2G)
Energy arbitrage: Buy electricity during low price hours and sell them during high price hours. (Applicable for V2G)

Great Britain, the Netherlands, Switzerland, France and Belgium still have preference for the traditional time of use pricing[45]. However, as of Nov 2021, the number of smart meters in Germany is still lacking. This has led to majority of utilities in Germany to still have a flat energy tariff.

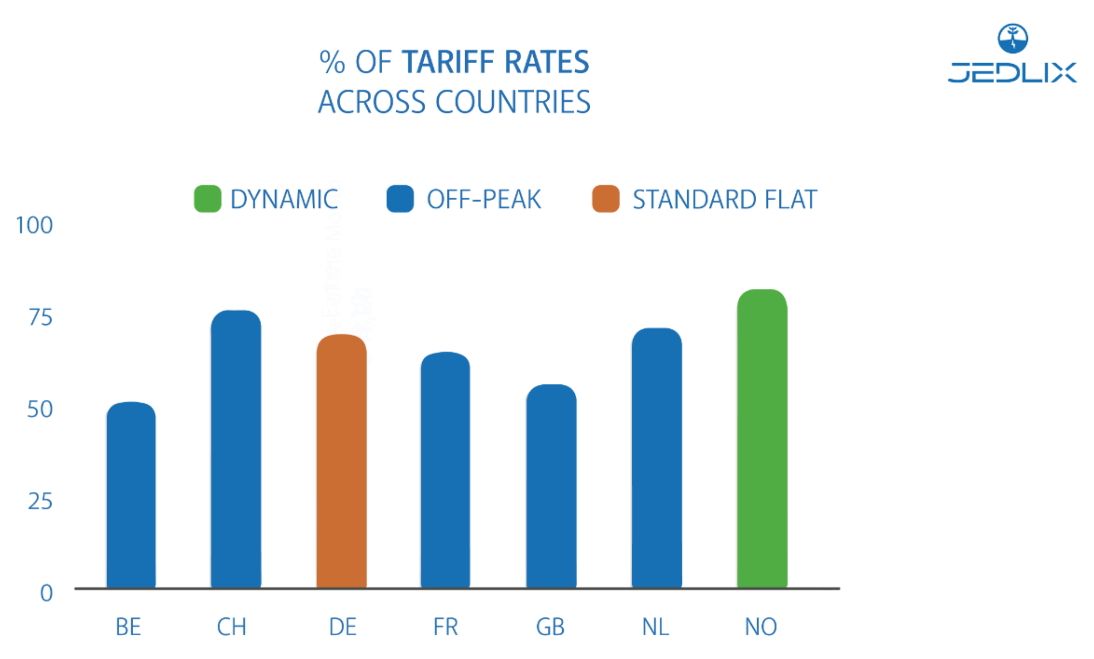

Figure 4:4: The type of energy tariff structure across the different utilities in the respective countries[46] (BE: Belgium, CH: Switzerland, DE: Germany, FR: France, GB: Great Britain, NL: Netherlands, NO: Norway)

4.1.2.2 Energy Market Products

One of the commercial avenues for V2G to be profitable is to enable the EVs to participate in the energy markets. The current crop of energy market products in India are given in Figure 4:5.

- ***Day Ahead Market (DAM):*** DAM is an electricity trading product for buying/selling of electricity at 15-minute time blocks for the next day. The price and quantum of

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[45] Europe Economics, "International Review of Tariff Structures:, July 2021, https://www.cru.ie/wp-content/uploads/2021/10/CRU21123a-Advisor-Report-International-Review-of-Tariff-Structures.pdf

[46] Jedlix, "A sneak peek into tariff rates across countries", Nov, 2021, https://www.jedlix.com/news/tariff-rates-accros-countries

energy to be traded are discovered through a double sided closed auction bidding process.

- ***Green Day Ahead Market:*** The green day ahead market is also similar to the day ahead market in which the clearing takes place in a sequential manner, i.e. the renewable segment with must-run status are cleared first followed by the conventional segment.
- ***Real Time Market (RTM):*** RTM allows for trading of electricity to be delivered an hour after the bids are made. So, the RTM allows for trading of electricity much closer to the delivery period compared to DAM.
- ***Term Ahead Market (TAM):*** It provides a range of different products where the participants can trade electricity on a term basis for a duration of up to 11 days ahead. The products under TAM include Intra-day trading, Day Ahead Contingency and Term Ahead contracts. Different products help participants to manage their energy portfolio under different time frames.
- ***Renewable Energy Certificates (REC):*** This product was introduced by the Central Electric Regulatory Commission to ease the purchase of renewable energy by the different state utilities and other obligated entities. One REC represents 1 MWh of energy generated solely from renewable energy resources.

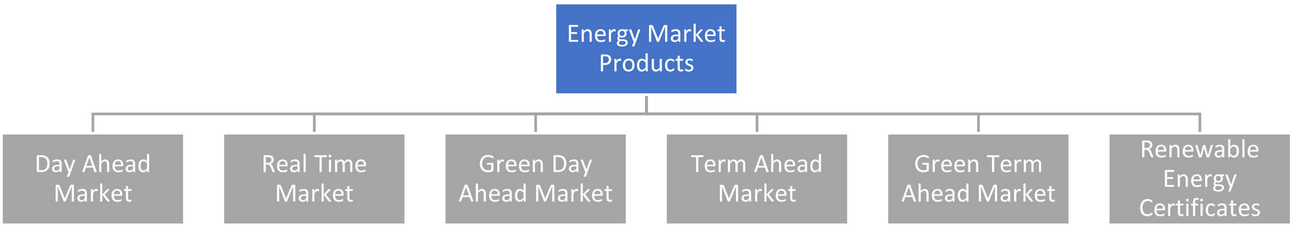


Figure 4:5: Energy market products in India

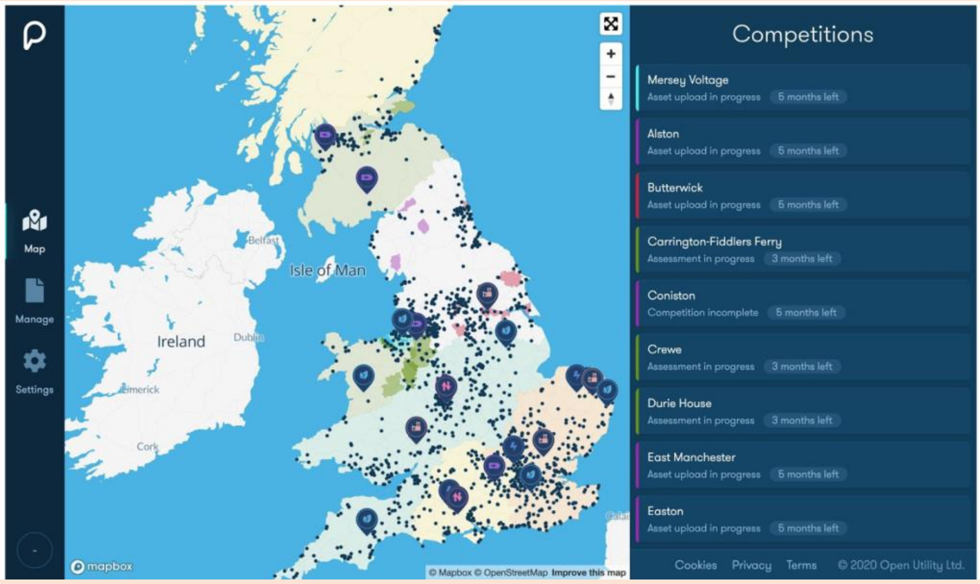
To participate in these market products however, the resources need to be connected to the transmission network (i.e. 132 kV and above), which may be feasible for large charging stations at bus depots, but may prove to be a significant barrier for other commercial PCSs. Further, for utilization of the transmission network the entities would need to have a GNA as mentioned in Section 4.1.1.4.

4.1.2.3 Distribution System Operator Products

Utilization of V2G for solving issues of the distribution network operator such as congestion management, reactive power management may provide much value. Also, as the EVs would generally be also connected to the distribution network as opposed to the transmission network, utilization of EVs for provision of these support services would be much easier. However, there is need for adequate remuneration regulations facilitating the use of EVs for distribution grid support services.

An illustrative example pertains to the reactive power requirements in the distribution network. Distribution Companies (DISCOMs) frequently issue tenders for the procurement of resources capable of supplying reactive power, including capacitor banks, STATCOMs, and other technologies. Considering the capacity of V2G (Vehicle-to-Grid) chargers to provide reactive support, it raises the question of whether a viable market structure can be formulated to ensure fair compensation for the provision of reactive power support by V2G chargers.

A new market has been developed to cater to the flexibility requirements of the distribution system in UK. Called PicloFlex, it provides a single standardised bidding and qualification interface for participants. The local grid support services are floated as requirements and registered assets can participate in these services.



Competitions

Mersey Voltage
Asset upload in progress 5 months left

Alston
Asset upload in progress 5 months left

Butterwick
Asset upload in progress 5 months left

Carrington-Fiddlers Ferry
Assessment in progress 3 months left

Coniston
Competition incomplete 5 months left

Crewe
Assessment in progress 3 months left

Durie House
Assessment in progress 3 months left

East Manchester
Asset upload in progress 5 months left

Easton
Asset upload in progress 5 months left

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Figure 4:6: Snapshot of the PicloFlex webpage showing the different available competitions[47]

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[47] Dashboard, PicloFlex, https://picloflex.com/dashboard

4.1.2.4 Ancillary Services

Another value stream where V2G has shown much potential is the provision of ancillary services such as frequency regulation, frequency contingency reserves etc. Ancillary services can be classified into the following four categories as shown in Figure 4:7. *Frequency support services* try to maintain the frequency with in the nominal operating ranges by controlling the active power generation and demand in the network. *Voltage support services* maintain the reactive power balance and help maintain the voltage of the system within operating limits. It is compulsory in most of the countries, while few other countries the reactive power is procured either through bilateral contracts or tendering process[48]. *Ramping services* enable the fast change of active power. It is procured in terms of megawatt of ramping required per unit time. This time can be a certain duration such as 5 mins. *System restoration* services are utilized to restore the system after a major disturbance has led to black-out, brown-out of the grid.

As of 2022, in India the Primary Reserve Ancillary Service (PRAS), Secondary Reserve Ancillary Service (SRAS) and the Tertiary Reserve Ancillary Service (TRAS) are the three available ancillary services. PRAS is an automatic response delivering reserve power in negative proportion to grid frequency change and a mandated response as per the Indian Grid Code. SRAS and TRAS are yet to be rolled out as a commercial product in the electricity market for resources to bid into.

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[48] Forum of Regulators, "Report on Intra -State Reserves and Ancillary Services for Balancing", Jan 2020, http://www.forumofregulators.gov.in/Data/Reports/SANTULAN-FOR-Report-April2020.pdf

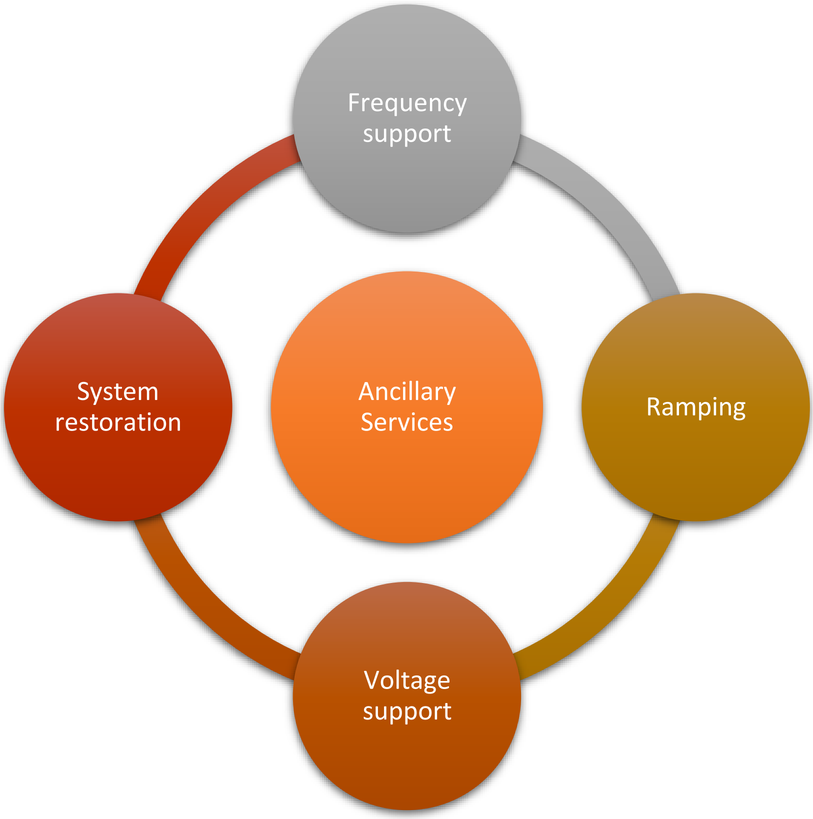

Figure 4:7: Classification of ancillary services

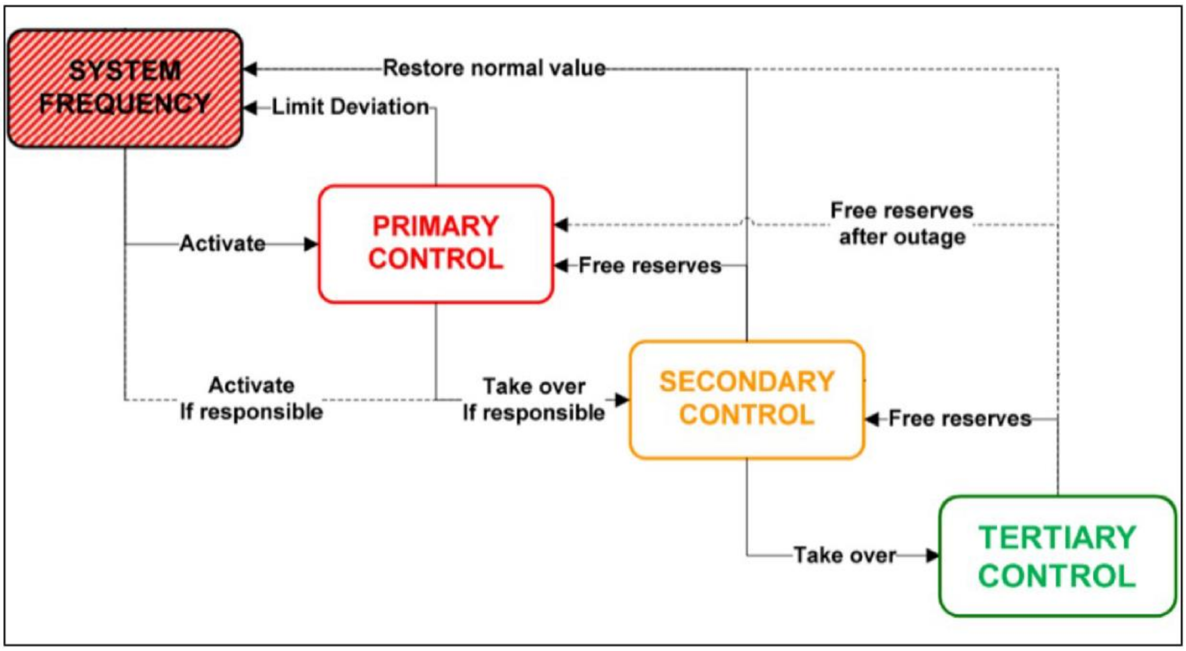

Figure 4:8: Activation and deployment of reserves for frequency support [49]

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[49] Forum of Regulators, "Report on Intra -State Reserves and Ancillary Services for Balancing", Jan 2020, http://www.forumofregulators.gov.in/Data/Reports/SANTULAN-FOR-Report-April2020.pdf

- **Secondary Reserve Ancillary Services:** The role of SRAS is to bring the system frequency back to the nominal value post a contingency and after the primary reserves have been deployed. SRAS shall be activated and deployed by the Nodal Agency to maintain/restore grid frequency within the allowable bands. For an entity to be eligible as an SRAS provider, the entity (standalone or aggregated) connected to Inter State Transmission System or Intra State transmission System and if it,
    - has bi-directional communication system with regional load dispatch centre (RLDC);
    - is automatic generation control (AGC)-enabled, in case of a generating station.
    - can provide minimum response of 1 MW;
    - has metering and SCADA telemetry in place for monitoring and measurement of energy delivered under SRAS, as stipulated in the Detailed Procedure by the Nodal Agency;
    - can respond to SRAS signal within 30 seconds and providing the entire SRAS capacity obligation within fifteen (15) minutes and sustaining at least for the next thirty (30) minutes.
- **Tertiary Reserve Ancillary Service (TRAS):** For an entity to be capable of participating in TRAS in India it should be able to,
    - vary its active power output or drawl or consumption on receipt of despatch instructions from the Nodal Agency; and
    - provide TRAS within 15 minutes and sustaining the service for at least next 60 minutes.

One of the major obstacles for EVs to participate in ancillary services in India is the requirement of connectivity to the transmission network, which may be difficult for Public Charging Stations (PCS). Also, the remuneration for the provision of these services is still unclear as these are not available in the electricity market as of 2022.

One of the most lucrative services for V2X applications is participation in frequency regulations products as shown in

.

In frequency regulation, the V2X entity responds to change in system frequency during normal operating conditions (i.e., there is no contingency event in the system). The goal of frequency regulation is maintain the system frequency within the normal operating frequency region. However, in India such regulation service is not yet in operation.

How can utilities prepare for DER integration?

Having DERs such as electric vehicles which can participate in the different energy markets can pose a significant challenge for the local distribution network operators. While DERs have a huge potential for scalability, it implies that the traditional centralized top-down resource planning may prove itself to be inadequate[50]. The local distribution network operators need to undertake some crucial steps to leverage the maximum benefit from this resource.

- The first step for the distribution network operator is to establish a baseline understanding of their network through modelling using real life data. For this the network operator would need to invest in the advance metering infrastructure (AMI) for the network. Once the AMI is in place, it can use the data collected to replicate the network in a simulation environment and simulate the implications of DER addition.
- The utilities would also need to perform analytics on the data collected. The goal of this analytics is to have a close to real-time understanding of the condition of the distribution network. This would allow the utility to have an adequate assessment of the distribution system needs and allocate the resources accordingly. However, once the utility starts collecting data, the repository of the data can grow exponentially, and the utility would need a resource in the form of a data analytics system (may need dedicated data centres and experts on data analysis) to manage it properly.
- With aggregation of DERs, the utilities may have to manage several aggregators and so would have to create clear rules for participation of these aggregators, along with management platforms to optimize this interaction.

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[50] Gupta, Abhay, "FERC Order 2022 is Coming: Here's How Utilities Can Prepare", Forbes, June 2022. https://www.forbes.com/sites/forbestechcouncil/2022/06/13/ferc-order-2222-is-coming-heres-how-utilities-can-prepare/?sh=26e4ac1f7d4d

4.1.3 Policy Requirements

Looking at the nascent stage of V2G in the country the role of policies is to start the V2G ecosystem in the country. This would require making V2G commercially viable as well increasing the awareness of the public regarding V2G and its applications. The EV users are still not educated about V2X, its applications and potential benefits. The current state EV policies and central schemes in India have made no consideration of V2G applications.

4.1.3.1 Policies for increasing V2G awareness

The lack of knowledge about V2X makes the users sceptical to adopt the technology. This has proven to be one the most crucial barriers of V2X implementation as discovered in numerous surveys and pilot studies[51,52].

4.1.3.2 Policies and incentives for V2G applications

As already highlighted in Report 1 and Report 2, the initial investment necessary for V2G applications is one of the prohibitive factors. Policies that offer incentives would ease the initial cost of capital for V2G stakeholders helping the V2G market to develop.

4.1.3.3 Policies for incorporation of pilot studies

Understanding the challenges, barriers and potential of V2G in the Indian ecosystem would need pilot case studies exploring V2G applications in detail. However, no such pilot studies have yet been conducted in the country.

Innovate UK is the UK's national innovation agency. It has provided funding of 8 projects to explore the feasibility of innovative V2G business models in UK. These projects have led to real life commercial products, that are currently being tested on the public. More than 2700 vehicles are being trailed in these projects covering different customer types and geographical areas. Thus, the projects are helping in not only demonstrating the business models for V2G but are also giving insights to user

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[51] Kester, Johannes, Gerardo Zarazua de Rubens, Benjamin K. Sovacool, and Lance Noel. "Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study." Transportation Research Part D: Transport and Environment 74 (2019): 277-293.

[52] Noel, Lance, Andrea Papu Carrone, Anders Fjendbo Jensen, Gerardo Zarazua de Rubens, Johannes Kester, and Benjamin K. Sovacool. "Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment." Energy Economics 78 (2019): 525-534.

engagement, and whether the UK populace is willing to participate in this technology[53]. The different projects funded by Innovate UK are given in Table 4.2

Table 4.2: Projects funded by Innovate UK on V2G applications

Project title	Category	Duration (months)
V2Go	Fleet based trial and customer profiling and suitability for V2G services	36
E-Flex	V2G enabled fleets in urban area	30
Powerloop	Implementation of domestic V2G systems	36
SMARTHUBS Demonstrator	Integration of V2G, battery and PV into a smart hub	36
Bus2Grid	Evaluation of V2G services from buses	36
E4Future	Validations of stacked V2G services under diverse scenarios	36
EV-elocity	Customer acceptance and business viability of fleets and airports	36
Sciurus	Implementation of VPP and bundling of energy services	24

4.1.4 Hardware and software requirements

4.1.4.1 Hardware

To enable V2G, there is need for hardware capable of V2G applications. These include V2G capable chargers, EVs, metering infrastructure as well the grid infrastructure.

As for chargers, the only V2G capable charger in the market as of 2022 are CHAdeMO chargers. However, most 4-wheeler EV models in India come equipped with the CCS connector type[54]. So, the practicality of placing V2G capable CHAdeMO chargers if there are no EVs that are capable of using these chargers begs question. However, with the release of IEC 15118-20 standard, CCS are chargers with V2G capability are expected to be rolled out soon (Wallbox Quasar 2, a CCS V2G charger is already in the works and is expected to be available commercially in the very near future[55]). Along with chargers, there is also requirement of EVs capable of bidirectional charging. Currently, EVs with CHAdeMO charging standards are the only EV models capable of V2G as given in Section

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[53] Innovate UK. https://www.ukri.org/councils/innovate-uk/

[54] Zakir Rather, Angshu Nath, Dhanuja Lekshmi, Rangan Banerjee, "Integration of Electric Vehicles Charging Infrastructure with Distribution Grid: Global review, India's Gap: Analysis and Way Forward Electric Vehicle Charging Infrastructure and its Grid Integration in India Status Quo, Critical Analysis and Way Forward", GIZ, 2022.

[55] Wallbox Quasar 2. https://wallbox.com/en_us/quasar2-dc-charger.

2.3.1.3.2 of Report 1. Also, to tackle the high capital investment needed for DC V2G, significant R&D effort has also been put on AC V2G (We Drive Solar is one such demonstration project, where AC V2G is being explored[56]).

As for the grid and the metering infrastructure, the requirements would be similar to the installation of other similar distribution generation resources such as rooftop solar PV, battery storage unit etc. There is need for smart metering infrastructure, that would enable the time based logging of energy usage while also facilitating communication regarding energy tariffs.

4.1.4.2 Communication protocol and Software

Facilitation of V2G needs well developed software packages as well robust interoperable communication protocols. The data requirement for enabling V2G is already mentioned in Section 4.1.1.3. The software and the associated communication protocols enable this data transmission between the different concerned entities.

CHAdeMO protocol is used in the CHAdeMO chargers and is the only communication protocol between EV and Electric Vehicle Supply Equipment (EVSE) that enables V2G capabilities as of 2022.

IEC/ISO 15118 protocol between the EV and the EVSE unlocks the bidirectional charging capability for CCS based chargers. As CCS chargers are more likely to be installed in India compared to CHAdeMO chargers, this protocol is significant.

The Open Charge Point Protocol (OCPP) is used for communication between the EVSE and the CPO. It exchanges the details of the charging event such as the start time of charging, the stop time of charging, energy traded, charging status etc. The core philosophy of OCPP is to provide an open-source communication protocol to make any EV charger work with any charging management software even if manufactured by different OEMs. OCPP 2.0.1 also supports bidirectional communication between the CMS and the EVSE which allowed for a more sophisticated smart charging application. It also included support for the ISO/IEC 15118 protocol.

The Open Smart Charging Protocol (OSCP) communicates the forecasts of available capacity in the distribution network from the distribution system operator to the CPO. It

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[56] We Drive Solar. https://www.wedrivesolar.nl/

can be used between the DSO and the CPO as well as between the CPO and the Home Energy Management System (HEMS) to transmit a 24-hour capacity forecast.

The **Open Automated Demand Response (OpenADR)** enables smart charging and demand response capabilities in the EV ecosystem. It facilitates open and interoperable demand response solution using pricing signal, capacity availability from DSO, load demand from clients and other relevant information. The protocol is a highly secure, open, smart grid protocol. The standard is also available in version 2.0 and allows the exchange of price signals, setpoints, and metered values between loads, electric storage, distributed generators, and EVs on the one hand, and energy providers and aggregators on the other.

IEEE 2030.5 is an internet protocol (IP) based application protocol for smart metering and automation of demand/response and load control in local or home are networks[57].

4.2 Enabling V2H, V2B in India

Vehicle-to-Home (V2H) and Vehicle-to-Business (V2B) systems have comparatively simpler regulatory demands than Vehicle-to-Grid (V2G) due to their limited scope. Unlike V2G, V2H and V2B setups operate in isolated environments, and energy is not exported back to the grid, eliminating the need for complex technical grid interconnection regulations. Besides having suitable hardware, Figure 4:9. illustrates the regulatory and policy prerequisites for V2H applications.

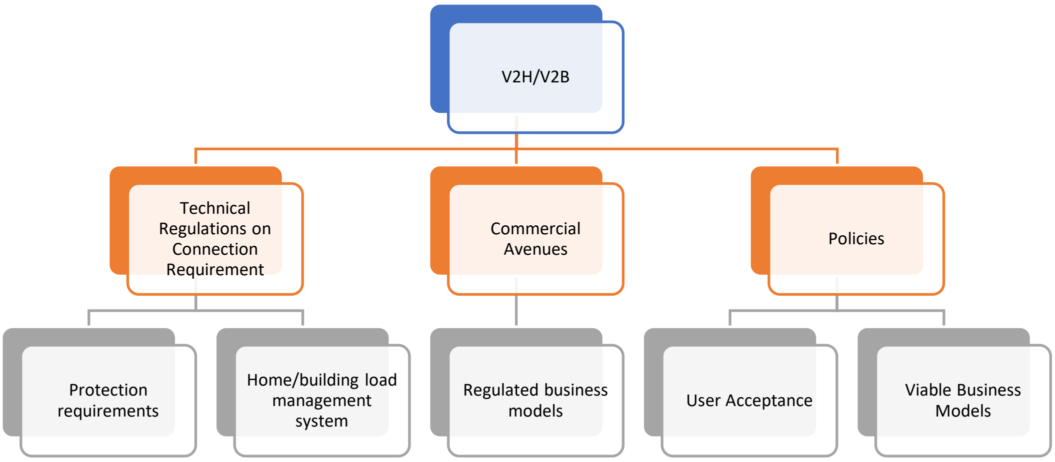

Figure 4:9: Policy and regulatory requirement for V2H/V2B

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[57] Mater, James; Kang, Steve and Simpson, Robby "IEC 61850 and IEEE 2030.5: A Comparison of 2 Key Standards for DER Integration: An Update" https://cdn2.hubspot.net/hubfs/4533567/IEEE-2030-5-and-IEC-61850-comparison-082319.pdf

4.2.1 Technical Regulations for V2H/V2B

4.2.1.1 Protection and safety requirements

As in V2H/V2B applications power is not fed from the EV to the grid, so the grid interconnection regulations are not needed. However, the protection and safety requirements are still necessary to facilitate the safe utilization of V2H/V2B as an energy generation unit. These protection requirements include regulations for,

- Overcurrent protection
- Over and under voltage protection
- Thermal protection

Further, as the V2H/V2B units would operate in isolation with the grid, they also need to have an anti-islanding detection functionality to ensure that the grid is not connected to the network while being powered from the V2H/V2B unit.

4.2.1.2 Need for home/building load management services

As V2H and V2B are used for optimizing the local energy consumption of the property, there is requirement of a load management system (LMS). The load management system would optimize the charging of the EVs as well as manage other smart loads in the property as required. Enabling the load management system requires a regulated architecture for the communication between the different involved entities. Also depending on the use case each of the individual architectures can vary[58].

4.2.1.3 Smart Meter Installation

As seen from the architectures mentioned in Section 4.2.1.2, there is a need for smart meter for utilization of V2G as V2H/V2B resources. The smart meter has basically two jobs.

- To log the energy consumed by the household for each time slot.
- Provide the time-based energy charges to a LMS in the household to optimize the household load.

The smart meter requires a communication infrastructure to relay the necessary information. Regarding communication of data, there are two aspects here,

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[58] More details on the architectures are provided in Chapter 10.

- Communication between smart meter and the in-home display[59] (i.e. availability of data for the user)
- Communication between the smart meter and the energy supplier for daily logging of energy use.

The in-home display receives data from the smart meter at every 10 seconds, while electricity retailers collect data from Smart Meters once a day or as required by the local energy retailer[60].

4.2.2 Commercial Avenues

Unlocking the potential of V2H/V2B requires revenue generation opportunities for the users. The different use cases for V2H/V2B are

- To use the vehicle as storage and avoid consumption during peak periods.
- To increase the utilization of local energy generation
- For power use beyond the contractual demand of the residence.
- To power an overall off-grid system (islanded operation)

Utilization of V2H/B can be considered as an extension of V1G as now in addition to just controlling the charging power of the vehicle, power can be also fed back from the vehicle. This increases the amount of flexibility that can be provided by the EV.

4.2.2.1 Time based EV tariffs

The most critical necessity for value addition of V2H/V2B is the presence of time-based EV tariffs. This would allow the EV user to optimize the charging as well as reduce the total load during peak periods to minimize their energy bills. Although time-based tariffs are available in most states in India, very few of them are for residential customers. Most time-based tariffs in India are for commercial or industrial customers.

Octopus Agile shown in Figure 4:10, is a dynamic tariff available in UK. As can be seen, under the Agile tariff there is a significant different between the peak prices which is about 35 pence/kWh and off-peak prices which is about 5-10 pence/kWh. So, it

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[59] The In home displays allows the user to monitor and check the energy consumption of the household in real time allowing the user to better manage their energy consumptions.

[60] Smart Meter Data. https://www.smartme.co.uk/meter-data.html#gsc.tab=0 © SmartMe.co.uk

provides a significant window for users to shift their energy usage and have significant cost savings.

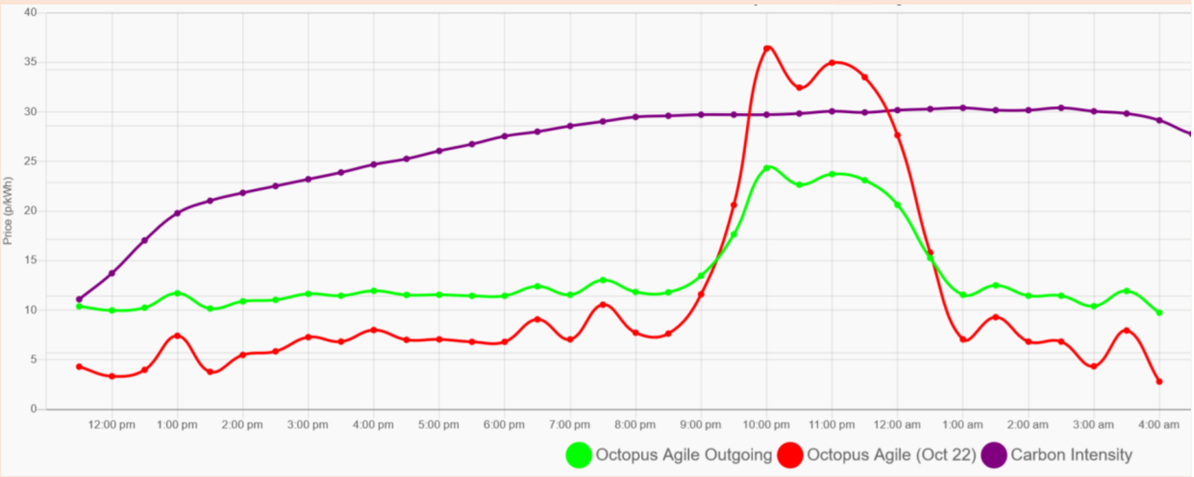

Figure 4:10: Octopus Agile tariff (both for import of power and export of power) shown for the month of October 2022[61]

4.2.3 Policy Requirements

Similar to V2G, for V2H/V2B applications, the role of policies is to give an impetus to start the V2H/V2B ecosystem. In addition to the policies mentioned in Section 4.1.3, another policy that can help in V2H/V2B is the following.

4.2.3.1 Policies for smart homes

Policies for smart homes would help in the ecosystem growth of residential energy management solution. This would lead to growth of residential demand response systems, communication requirements, energy management devices, local renewable energy utilization etc. For example, Japan launched the 'Smart House & Building Standardization and Business Study Committee' which led to increased growth of the residential demand response, both from a technical and commercial standpoint.

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[61] Octopus Energy. https://smartathome.co.uk/octopus/

4.2.4 Hardware requirements

4.2.4.1 Hardware

Like V2G, the implementation of V2H/V2B services are possible only if the requisite hardware is present i.e. the vehicle and the charger should be able to offer V2H/V2B services[62]. Prior to connection of a V2X charger in the property, the following checks are needful.

- Adequate existing supply to cater to the increased load.
- Earthing arrangements for the incoming power supply.
- Authorization of installation by the respective DISCOM.
- The permission for installation of the equipment by the building authority or the other such authority.

The architecture for utilization of V2H to avoid consumption during peak hours is provided in Figure 4:11. The EV can function as an energy storage unit using architecture; it collects energy during times of low tariff for later usage within the home during times of high tariff. Here, the EV can also be utilized as an energy carrier, meaning it can be charged at one site with lower rates and then used to power a device at another at a higher rate. More loads beyond the property's contracted demand can be connected using the same architecture. In this case, the grid supply is used to power the loads up to the contracted demand, and the EV is used to power the remaining loads.

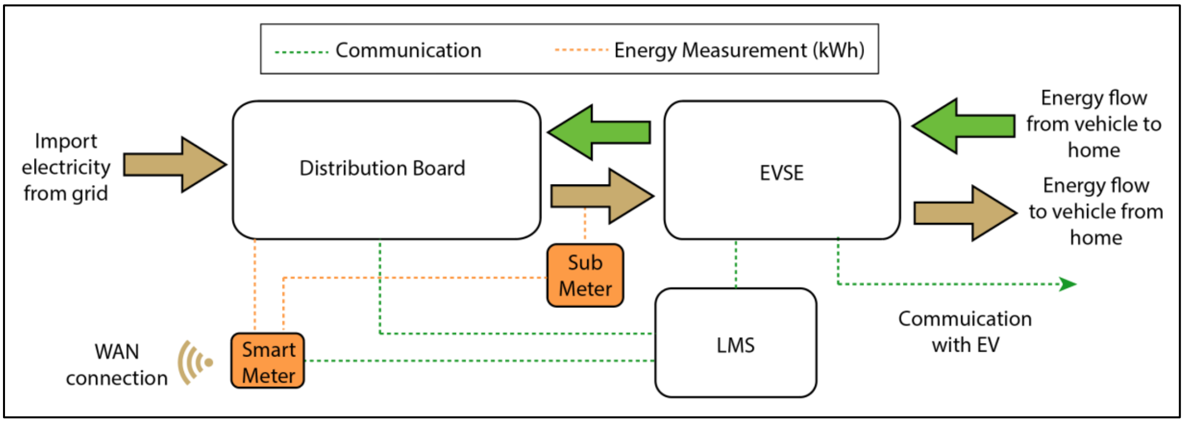

Figure 4:11: Architecture for using V2H/V2B to avoid consumption during peak periods

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[62] A charger designed to offed V2G services may not be capable of providing V2H services even though they both are capable of bidirectional power flow. V2G hardware are designed to operate in parallel to the other generators in the network, however V2H chargers are designed to operate in isolation as the sole generating unit in the system.

Using V2H/B it is also possible to provide back-up power to the residence when there is no power available from the grid. Also referred to as islanded operation, this situation may arise due to,

- A power cut in the system
- Designed as off-grid system

The architecture and connection diagram for using the vehicle as a storage unit to power the residence during islanded operation are given in Figure 4:12 and Figure 4:14 respectively. As shown in Figure 4:12, in the absence of supply from the grid, the LMS utilizes the energy stored in the EV and the generation from the on-site energy resource to supply power to the loads. In Figure 4:12, two separate circuits can be observed, one powered by the grid supply and other by the vehicle (with/without additional stationary storage unit). If the grid is available, the grid powers the entire residence. However, if there is a power cut i.e. the grid supply is no longer available, the back-up isolator which is normally closed is automatically opened by the LMS. This isolates the circuit powered by the vehicle from the mains. This is mandatory as otherwise the vehicle would try to power the entire the network.

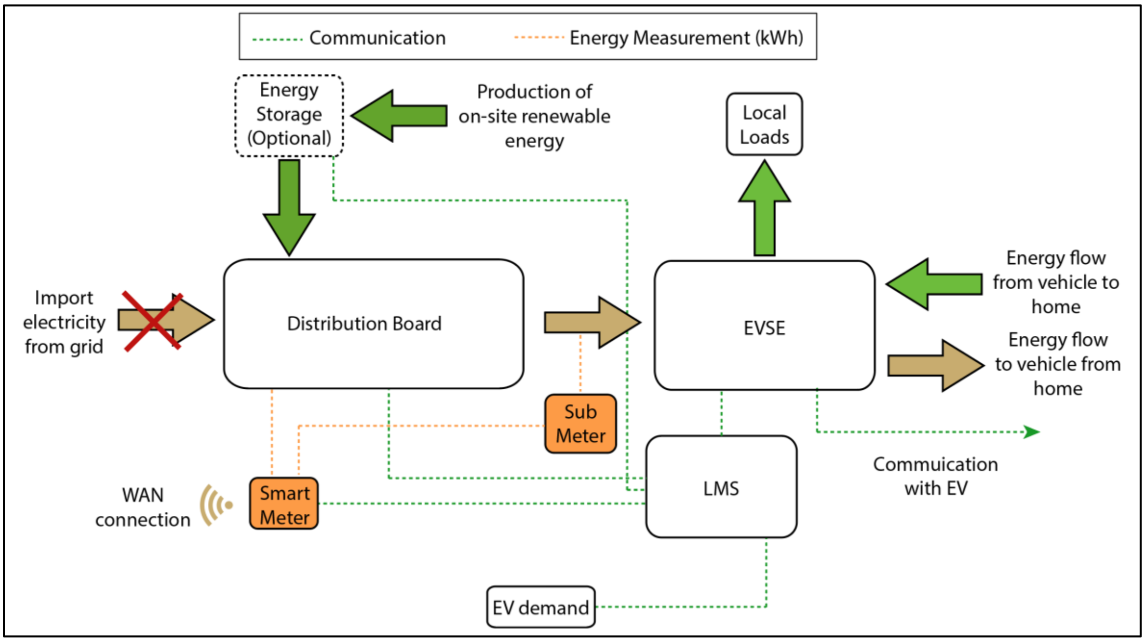


Figure 4:12: Architecture for using V2H/V2B in islanded mode

Figure 4:13 provides an architecture for using EVs for increased utilization of local energy generation.

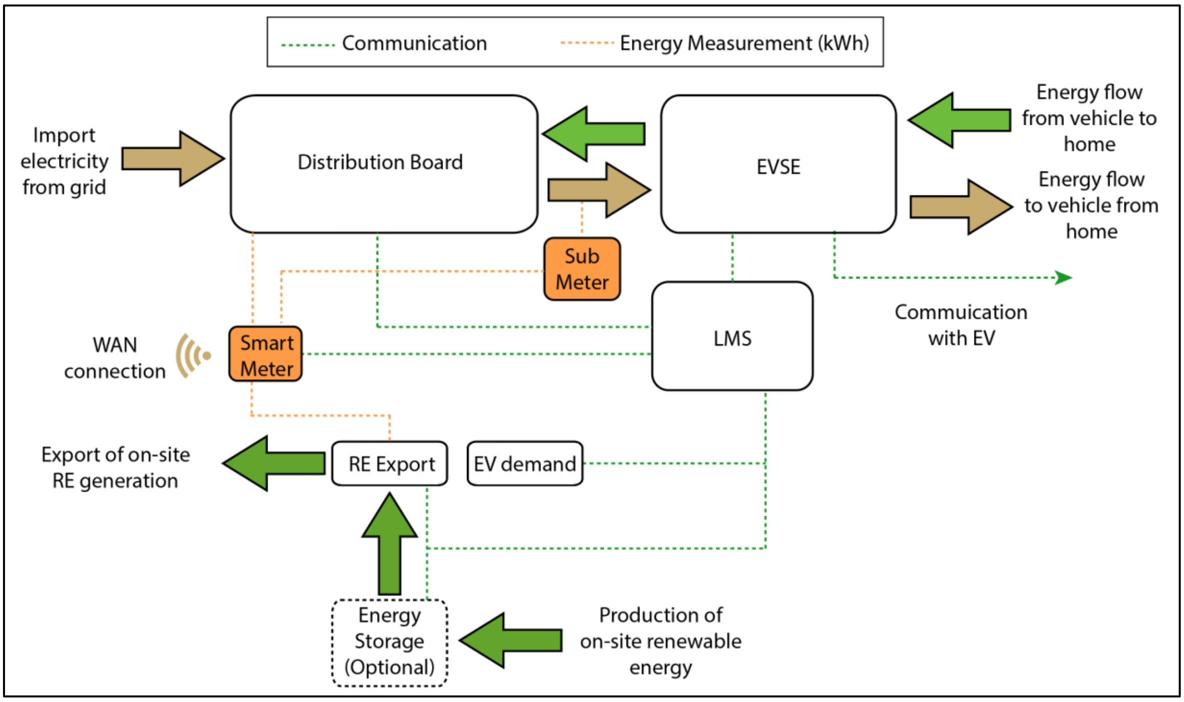


Figure 4:13: Architecture for using V2H/V2B for maximization of local energy generation usage

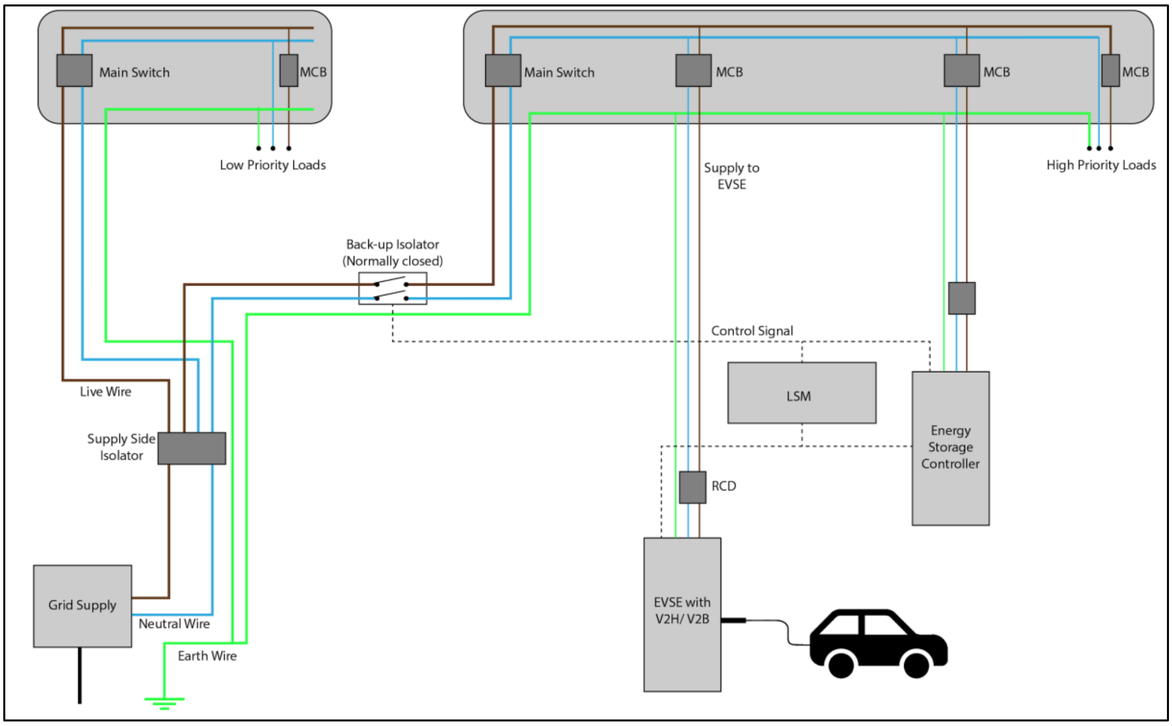


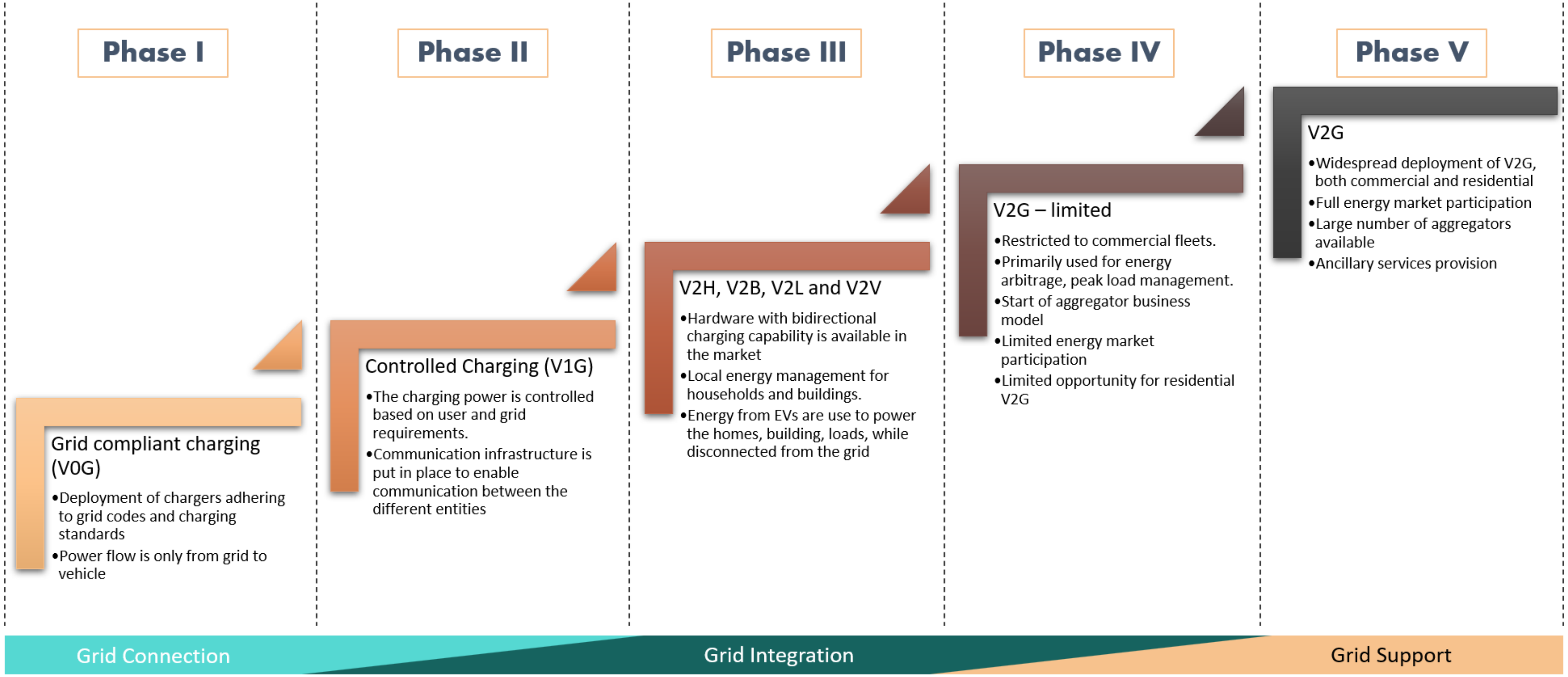
Figure 4:14: Schematic while using vehicle as a storage

4.3 Enabling V2V and V2L

V2V and V2L is quite unique as the requirements for these applications other than capable hardware is quite limited. Provided that there are regulations that guarantee that safety requirements are met, i.e. the use of these applications are done ensuring the safety of the user is maintained, V2V and V2L do not have other requirements. The commercial viability of V2L lies with the individual users, however V2V can help users with range anxiety and as a solution to a limited charging infrastructure.

4.4 Stages of development of V2X in India

The development of V2X in India can be divided into 5 phases as shown in Figure 4:15. Phase I and Phase II deal with connection of EV chargers with the grid, Phases II, III and IV deal with integration of EV chargers with the grid. While Phase IV and V, the EVs are used for grid support as well. Prior to development of V2X in India, V1G or smart charging needs to be implemented on a wider scale. Following smart charging, V2H, V2B and V2L are the next ideal applications due to the relatively lower regulatory requirements. Next, utilization of local renewable energy could be implemented with V2H and V2B applications. The use of V2G would initially be more favourable for customers with large fleets for lowering their total cost of operation. Further as the charging of the fleets would be predominantly concentrated in certain locations, the grid infrastructure can be adequately modified to cater to these customers. The applications of V2G in the initial phases would be mostly on energy balancing and arbitrage. School buses could also be included to the initial phase of V2G rollout due to their predefined operation timeline and their large battery capacities which makes them an ideal candidate for V2G. Simultaneously few technology understanding customers would also experiment with V2G during the initial growth periods. In the next phase of V2G, it will be rolled out to the masses, however still mostly for energy management, congestion management and the like. Ancillary services from V2G would likely be the final phase predominantly due to the stringent requirements necessary for provision for ancillary services.



Phase I

Grid compliant charging (V0G)

- Deployment of chargers adhering to grid codes and charging standards
- Power flow is only from grid to vehicle

Phase II

Controlled Charging (V1G)

- The charging power is controlled based on user and grid requirements.
- Communication infrastructure is put in place to enable communication between the different entities

Phase III

V2H, V2B, V2L and V2V

- Hardware with bidirectional charging capability is available in the market
- Local energy management for households and buildings.
- Energy from EVs are use to power the homes, building, loads, while disconnected from the grid

Phase IV

V2G – limited

- Restricted to commercial fleets.
- Primarily used for energy arbitrage, peak load management.
- Start of aggregator business model
- Limited energy market participation
- Limited opportunity for residential V2G

Phase V

V2G

- Widespread deployment of V2G, both commercial and residential
- Full energy market participation
- Large number of aggregators available
- Ancillary services provision

Figure 4:15: Phases of development of V2X in India

4.5 Role of storage in V2X

As highlighted in Section 4.4 of Report 1, energy storage can play in role in enabling V2X. But the impact is highly dependent on system characteristics and can vary on a case-to-case basis.

In the case of India, energy storge are allowed to be used either as standalone or used in complementary with other generation, transmission, and distribution utilities. Accordingly it can be granted connectivity to the grid under the Electricity (Transmission System Planning, Development and Recovery of Inter State Transmission Charges) Rules 2021[63]. This implies that these entities can be used for trading in the energy markets and participate in the different market products. However, the same is not clarified in the case of V2G enabled systems. So, one of the potential ways of utilization of V2G to participate in the energy markets is by integrating the V2G enabled charging station with an energy storage unit. So, while the energy storage will be trading with the energy markets, the V2G units can be utilized to play with the energy storage unit. Few of the grid connected storage systems commissioned in India are given in Table 4.3.

Table 4.3: Few of the grid connected storage systems in India[64]

Project	Capacity	Location	Commissioning
Power Grid Corporation Limited	3 x 500 kW, 250 kWh	Puducherry	2017
NLC	2 x 10MW Solar PV+ 8MWh/16 MW BESS	Port Blair	2019
NTPC	2MWh BESS	Port Blair	2019
NTPC	17 MW Solar PV + 6.8MWh/6.8 MW BESS	South Andaman	2019
NTPC	8 MW Solar PV + 3.2MWh/3.2MW BESS	South Andaman	2019
Tata Power Delhi Distribution Limited (TPDDL)	10 MWh	Sub-station, Delhi	2019

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[63] Ministry of Power, "Clarification regarding usage of energy storage systems (ESS) in various applications across the entire value chain of power system" 29th January, 2022.

[64] ISGF, "Energy Storage System: Roadmap for India: 2019-2032",

Solar Energy Corporation of India (SECI)	10 MW/20 MWh BESS for 160 MW Wind + Solar Hybrid	Andhra Pradesh	2019
SECI	2 MW Solar PV Project + 1 MWh BESS	Himachal Pradesh	2019
SECI	2 x 1.5 MW Solar PV + 1 2 x 2.5MWh BESS	Ladakh	2019
Andhra Pradesh State Electric Utility	5 MW Solar PV Project + 4MWh BESS	Andhra Pradesh	2019

Figure 4:16 shows the typical cost of components for Li-ion storage units in India. It is evident that major chunk of the CAPEX costs is due to the battery pack itself. Other related costs such as the associated power controller units can be reduced by co-locating with other generating resources (including V2G units). Co-location of energy storage with a PV generation unit result in reduction of total CAPEX by around 7.87%.

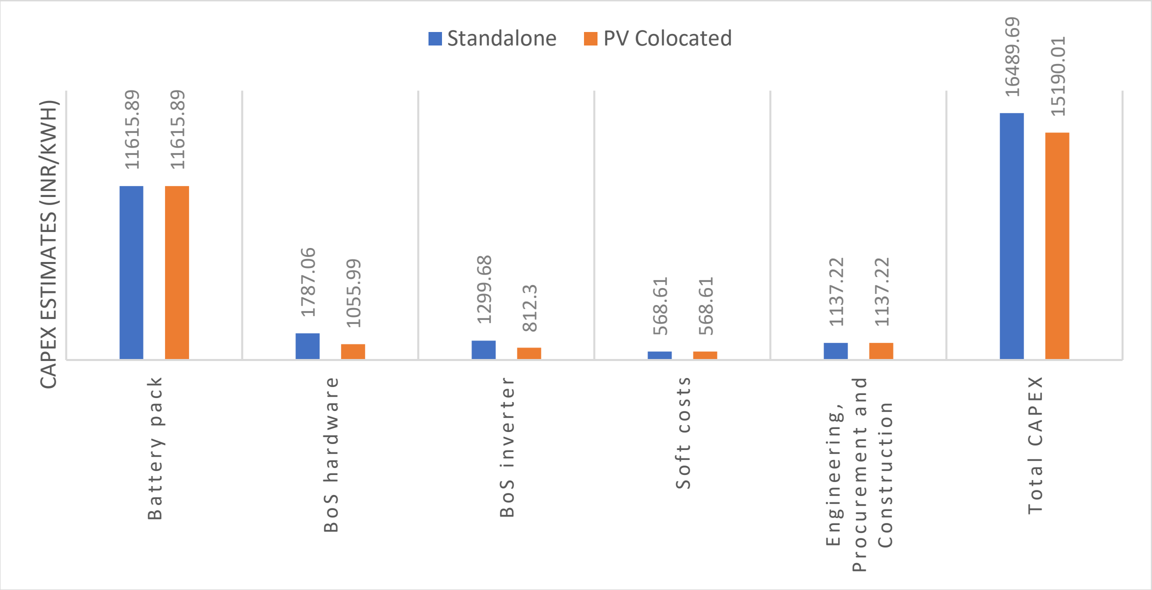

Figure 4:16: Cost of grid scale Li-ion storage installation in India with a capacity of 1MW/4MWh [65]

Also as seen in Section 10 of this report , storage units for use in residential or commercial units for V2H and V2B can lead to reduced operating costs. But the relatively higher cost of battery storage unit may not be financially viable. However, the cost of storage units is expected to reduce significantly in the upcoming years, which may turn the installation of

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[65] Deorah, Shruti M., Nikit Abhyankar, Siddharth Arora, Ashwin Gambhir, and Amol Phadke. "Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India." LBNL report (2020).

storage units for residential and commercial units to be profitable. The forecasted cost of grid scale storage units in India is given in Figure 4:17.

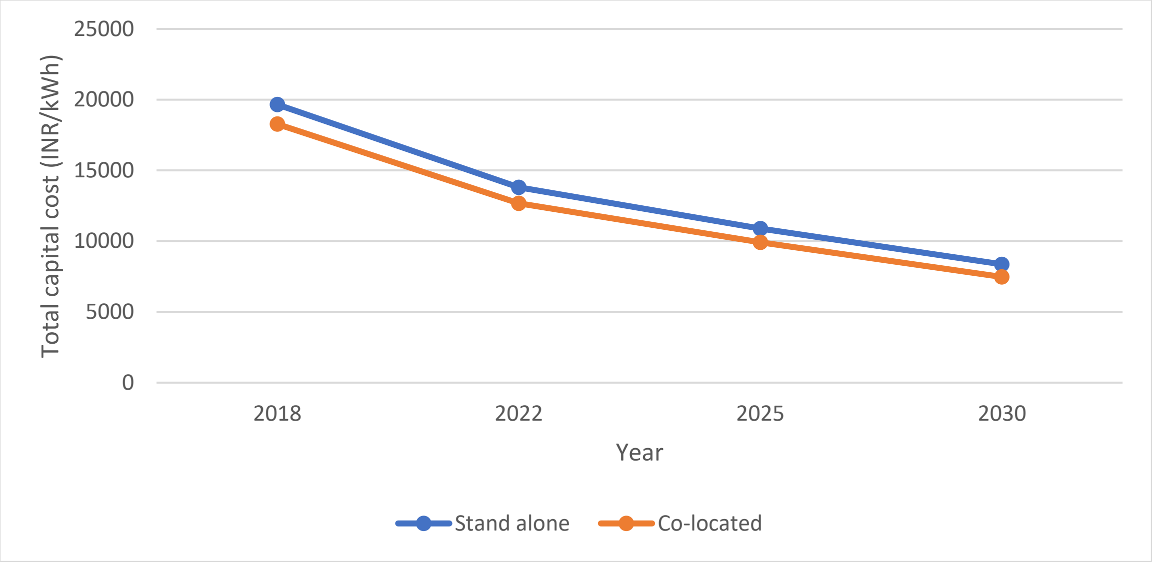

Figure 4:17: Forecasted cost of grid scale storage units in India[66]

4.6 SCADA requirements for V2X

Supervisory Control and Data Acquisition (SCADA) is a collection of equipment that can provide an operator with information to determine the status of a particular piece of equipment and can take actions accordingly. It is an integrated set of software, hardware, network and control subsystems that together provide real-time visibility and control of any plant. It plays a critical role in a number of industrial applications. SCADA systems in use today are capable of more than just data collection and device control. Without the assistance of humans, they evaluate data and make judgments using artificial intelligence (AI). Because of their ability to function in a cloud setting, SCAD\A monitoring and control may be carried out remotely utilising tablets and smartphones.

In V2G applications, SCADA will allow the following,

- View real-time and historical data such as
    - SoC levels in EVs
    - Voltage
    - Charger utilization etc.

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[66] Deorah, Shruti M., Nikit Abhyankar, Siddharth Arora, Ashwin Gambhir, and Amol Phadke. "Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India." LBNL report (2020).

    - Grid parameters such as line loadings, transformer loadings, phase voltages etc.
- Enable control of large number of individual V2G units
- Detect and resolve issues quickly
- Eliminate bottlenecks

SCADA achieves the applications mentioned above through four functions as mentioned below in Figure 4:18,

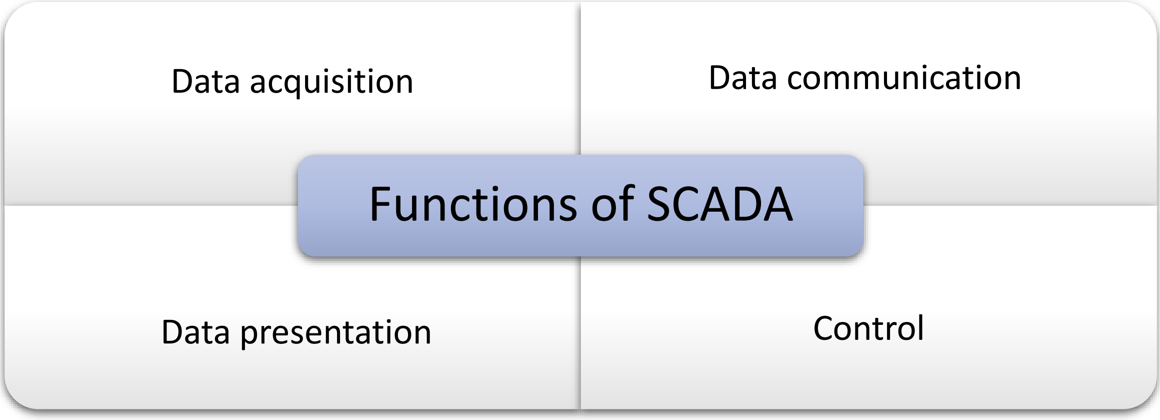

Figure 4:18: Functions of SCADA

4.6.1 Data acquisition

Using Remote Terminal Units (RTU)s and/or Programmable Logic Controllers (PLC), data is transferred from the field data interfaces to the central host. Different sensors and measurement devices form the field data interface devices that act as the eyes and ears of the SCADA system. These field data interface devices include

- Contact closures
- Protocol inputs
- Analog/digital sensors
- Serial output port

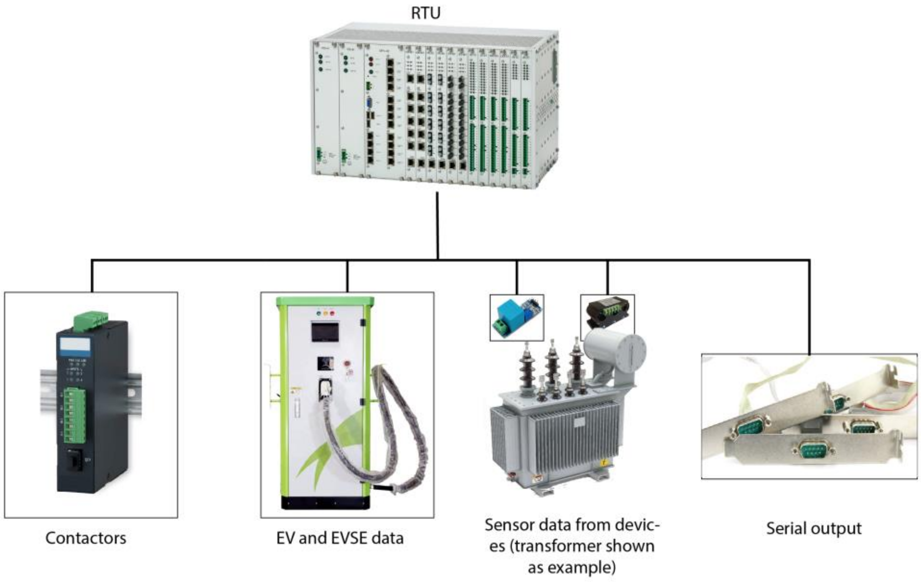

Figure 4:19: RTU collecting data from different field data interfaces

4.6.2 Data Communication

The data by the RTU/PLC from the field data interfaces then needs to be communicated to the central host. Two aspects need to be considered here, (i) the protocol used for data transfer and (ii) the transport medium used.

Different transport protocols can be used for data communication from the RTU to the central host, which include among others,

- Modbus
- Distributed network protocol (DNP3)
- IEC 60870 protocol
- High level data link control (HDLC)

Besides the protocol being used for communication, the physical medium used for communication is also of importance. The selection of the physical medium used for communication depends on the speed of communication required, the reliability, distance of communication as well as the budget. Few of the common physical mediums used for communication are,

- Local area network (LAN)
- Wide area network (WAN)
- Power line carrier

- Radio communication
- Serial communication
- Cellular communication
- Satellite communication

4.6.3 Data presentation

Once the data is collected it needs to be put in a presentable format so that the information is easily accessible to the operator. This can be achieved by multitude of different ways

- Human Machine Interface
- Dashboard, webpage, app
- Emails
- Voice messages

In the case of a V2G application, there can be a central control centre where the parameters of the different EVs and the charging points are being displayed in real-time. The operator can monitor the real time loading of the mains cable and control the charging speeds of the vehicles accordingly. When the charging is complete or if there is any energy demand response signal, an email/ alert/ SMS can be sent to the different users notifying the same so that they react accordingly. Also, in the case of stations spanning over a large area, the SCADA system can send out voice alerts over handheld radios in the case of emergency events.

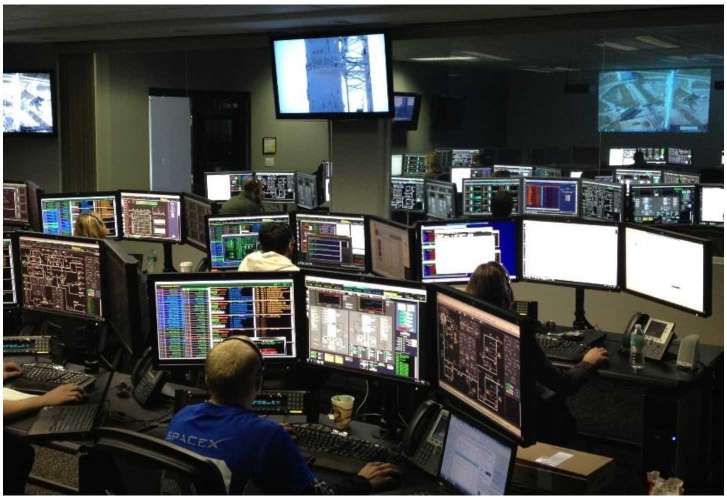

Figure 4:20: Illustrative SCADA control centre

4.6.4 Control

In addition to the information being presented to operators as mentioned in Section 4.6.3, control logics can also be programmed in the central SCADA server. These control logics would automate responses based on the operation status of the plant. This can include emergency actions such as removing a faulty equipment from the system, starting of a backup unit to replace the faulty equipment, changing the operational set point of equipment etc.

In the case of V2G, the SCADA can be designed to automatically respond to dynamically changing operational status of the charging station. For example, to restrict the overloading of the mains or to restrict the power drawn from the network to the contracted demand capacity, the SCADA can be programmed to regulate the charging power of the charging stations. This can be a simple switch on/switch off logic or a more sophisticated dynamic control of charging current. The SCADA can also be programmed to maximize RE generation usage by using the EVs as mobile energy storage units and control their charging / discharging accordingly.

Chapter 5. Modifications to Regulations, Policies and Technical Standards

5.1 Modifications to Grid Code Regulations

As mentioned in chapter 4, the existing grid code needs modification for V2X integration in India, this chapter highlights needful changes. *Here it is noteworthy that only needful representative modifications are mentioned here. Exact regulations are out of the scope of this report.* The modifications to the Indian grid code for integration of V2X should include the following,

5.1.1 Inclusion of V2X as a grid connected resource

The grid code should recognize V2X as a viable resource connected to the grid. International grid codes such as the Danish grid code have recognized V2X as a battery storage unit itself. This implies that the same interconnection regulations that apply to grid energy storage units are also applicable for V2X units. A similar approach could also be considered in terms of the Indian Grid Code.

5.1.2 Grid interconnection requirements

If a V2X resource is connected to the grid it should comply with the following requirements.

5.1.2.1 Normal operating regions

During normal operation (i.e., when there is no contingency in the grid) the resource needs to remain connected to the grid and operating as normal for predefined voltage and frequency bands as shown in Figure 5:1. As can be seen in the figure, between the frequency limits of f_1 and f_2 and the voltage limits of V_1 and V_2, the connected resource should be operating continuously. Between f_2 and f_4 and f_1 and f_3 the resource should maintain normal operation for at least x min, beyond which they are permitted to change the operation as per their requirement. Similarly, if the voltage exceeds the normal operating regions, the resource needs to be connected to the grid and maintain normal for a certain duration beyond which they are allowed to change their operation as needed.

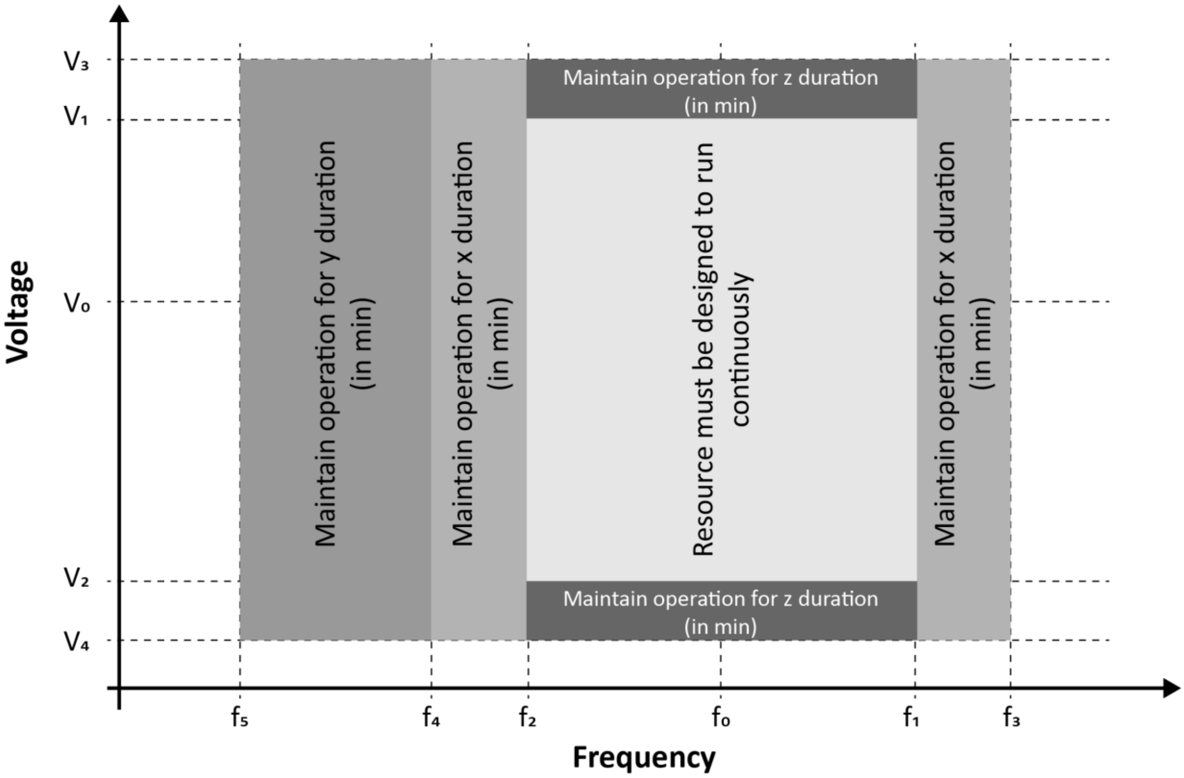

Figure 5:1: Requirements for operation of the V2X resource due to voltage and frequency variations during normal operating conditions (f_0 is the nominal frequency of 50 Hz. and V_0 is the nominal voltage of 1 pu)

5.1.2.2 Abnormal operating conditions

An abnormal condition is when there is an event in the grid such as faults in the network, tripping of transmission lines, generation outage etc. Such events lead to deuteriation of the operation conditions of the grid parameters. Under these conditions the requirement from the grid connected entities changes.

5.1.2.2.1 RoCoF tolerance

During the event of a loss of generation, instantaneous loss/change of load, there is a sharp change in the frequency of the grid. The rate of change of frequency (RoCoF) is the change of frequency as a function of time. The V2X entity must be able to withstand transient RoCoF changes up to a certain predefined limit.

5.1.2.2.2 Tolerance of voltage dips

At the point of connection, if there is a sudden drop in the voltage, the V2X entity should remain connected to the grid for predefined durations as defined in Figure 5:2.

- **Area A:** The V2X entity must remain connected to the grid and maintain normal operation.
- **Area B:** Within this region, the entity has to stay connected to the grid and provide voltage support as required by the grid operator.
- **Area C:** The entity is allowed to disconnect from the grid.

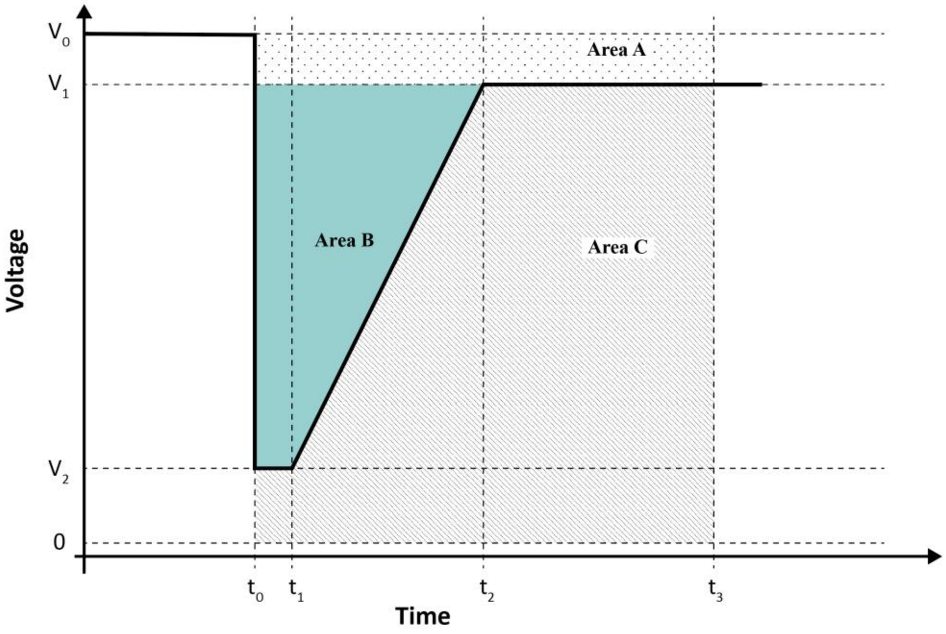

Figure 5:2: Illustrative tolerance requirements for voltage dips

During voltage dips, the grid operators can request V2X entities to participate in voltage support services using reactive power injection as shown in Figure 5:3.

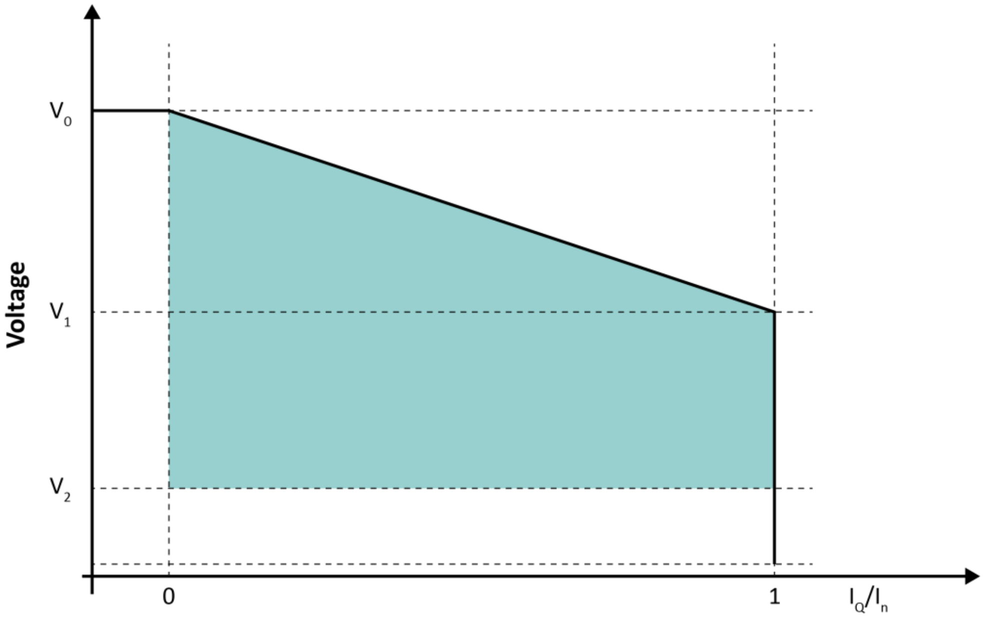

Figure 5:3: Requirement for delivery of additional reactive current I_Q during voltage dips (I_n is the rated current)

5.1.3 Power Quality

A grid connected entity must also comply with the power quality standards such as,

5.1.3.1 DC current injection

There is need to minimize DC current injection from the V2X resource on to the grid. As such, a regulation may added in the grid code that the allowable DC current injection is up to x% of rated current injection capacity of the V2X entity.

5.1.3.2 Current imbalances

There is also requirement to put regulations in place to curtail the current imbalances between the different phases.

5.1.3.3 Flickers

The V2X entity should not cause flicker contribution higher than predefined limits.

5.1.3.4 Harmonics

The V2X entity cannot emit harmonic currents higher than the threshold values to be determined by the competent authorities. An illustrative threshold values are given in Table 5.1.

Table 5.1: Threshold values for harmonic currents Ih/In (% of In)

	SCR	**Odd harmonic order h**							**Even harmonic order h**					
		3	**5**	**7**	**9**	**11**	**13**	**15**	**2**	**4**	**6**	**8**	**10**	**12**
U≤1 kV	<33	3.4	3.8	2.5	0.5	1.2	0.7	0.35	0.5	0.5	1.0	0.8	0.6	0.5
	≥33	3.5	4.1	2.7	0.5	1.3	0.7	0.37	0.5	0.5	1.0	0.8	0.6	0.5
	≥66	3.9	5.2	3.4	0.6	1.8	1.0	0.43	0.5	0.5	1.0	0.8	0.6	0.5
	≥120	4.6	7.1	4.6	0.8	2.5	1.5	0.5	0.5	0.5	1.0	0.8	0.6	0.5
	≥250	6.3	11.6	7.3	1.3	4.4	2.7	0.8	0.5	0.5	1.0	0.8	0.6	0.5
	≥350	7.5	15.0	9.5	1.6	5.7	3.7	1.0	0.5	0.5	1.0	0.8	0.6	0.5
U>1 kV	-	3.4	3.8	2.5	0.5	1.2	0.7	0.35	0.5	0.5	1.0	0.8	0.6	0.5

5.1.4 Control requirements

Beyond the above-mentioned requirements, the V2X entities should also have the following control capabilities. The control capabilities would enable these resources to participate in different grid support services.

5.1.4.1 Frequency response

The V2X entities should have the capability to control their active power based on the frequency of the grid. In the frequency deviations, this would enable the V2X entities to support the grid, akin to synchronous generators. The regulations also need to specify the time limits within which the V2X entity needs to respond the operating frequency and power margins.

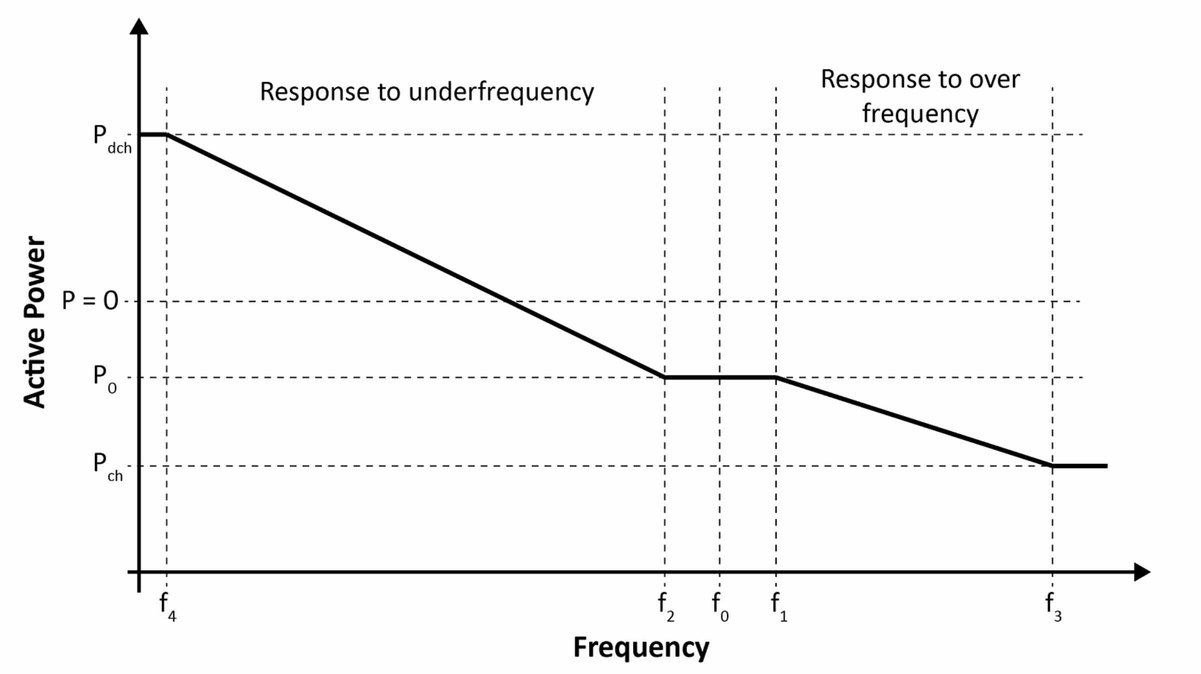

Figure 5:4: Illustrative frequnecy response characteristic for an V2X unit (P_0 is the charging power, P_{ch} is the maximum charging power, P_{dch} is the maximum discharge power)

5.1.4.2 Ramp rate limits

As V2X units are essentially battery storage units, they can change their active power almost instantaneously. In other words, they have very high ramping capability. Based on the requirement of the grid operator, they may need to restrict the allowable ramp rate of V2X entities so that the grid is not adversely affected.

5.1.4.3 Reactive power control

The grid code also needs to stipulate the reactive power control capability of the V2X unit. Based on the requirement, the V2X units would be designed so that their operating points always lie within the defined area as shown in Figure 5:5

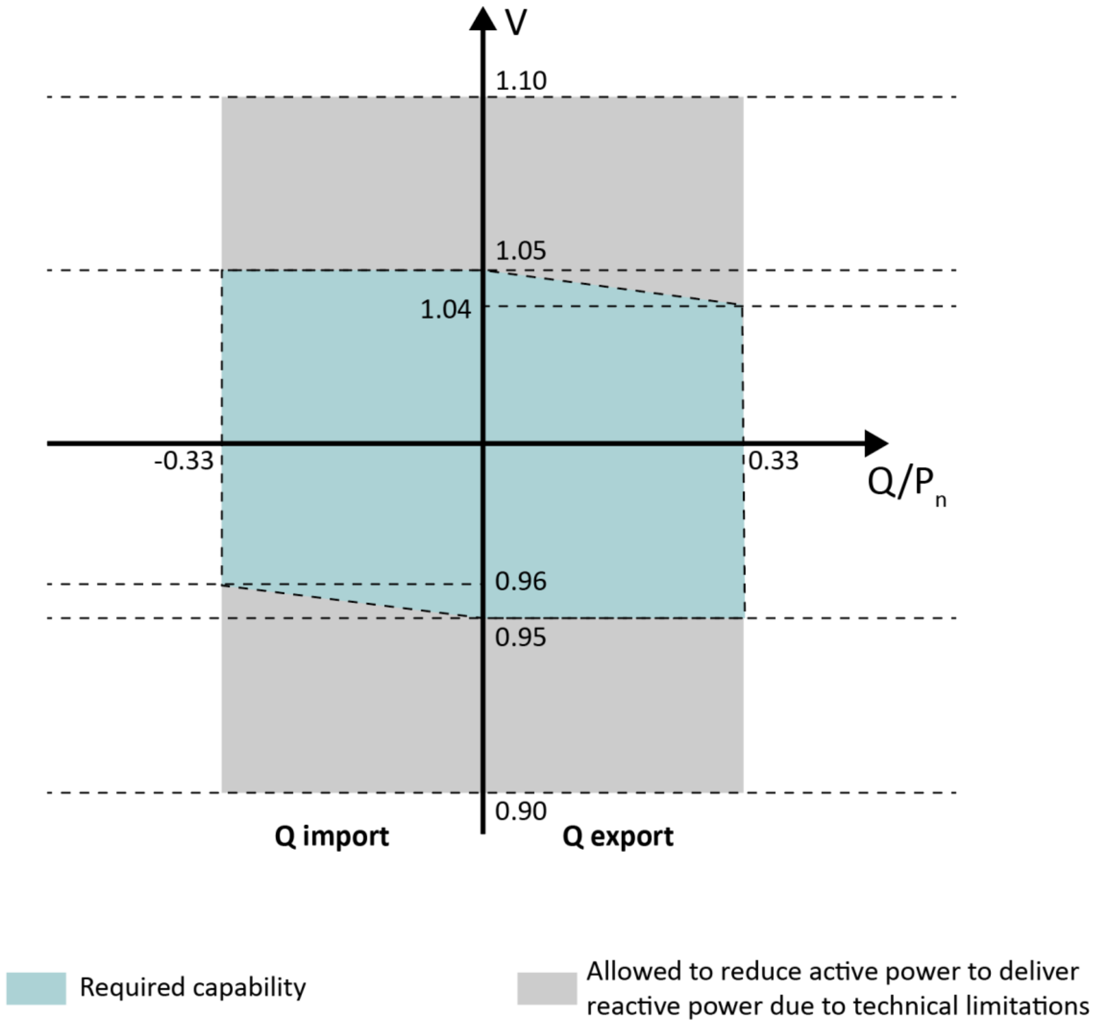

Figure 5:5: Requirement for delivery of reactive power as a function of the voltage at the point of connection (the values of voltages and Q/P_n *are only shown for illustrative purposes)*

5.1.4.4 Power factor control

In this control capability the power factor is controlled, i.e. the reactive power is controlled proportionally to the change in active power.

5.1.4.5 Voltage control

In voltage control, the V2X entity would control their reactive power imported/exported to ensure that the voltage is maintained in the voltage reference point. As shown in Figure

5:6, the Q set point for the V2X entity would change if the voltage deviates from the voltage set point as per the droop.

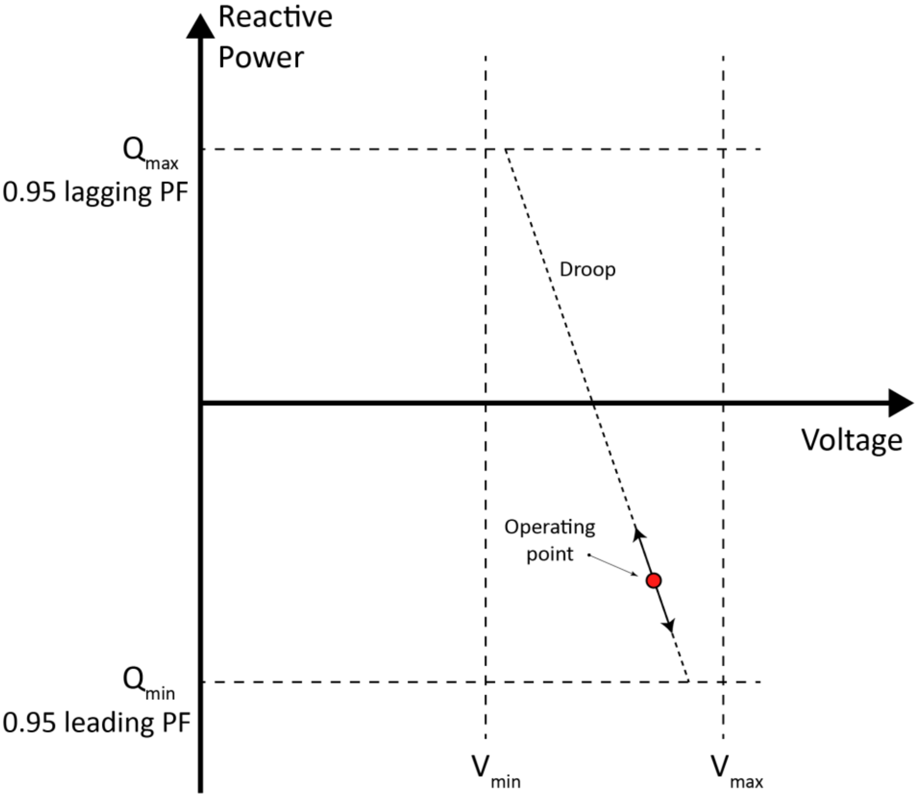

Figure 5:6: Voltage control for V2X entity (illustrative)

5.2 Modifications to Policies

5.2.1 Policies and Schemes of the Central Government

The two ongoing initiatives by the Government of India for EV ecosystem growth are the Automotive Mission Plan 2016-26 (AMP) and the second phase of Faster Adoption and Manufacturing of (Hybrid and) Electric vehicles (FAME II) scheme. One of the major focus of the AMP scheme is on boosting manufacturing, employment, mobility, and export, and also put forward vision on growing technologies like electric vehicles and associated infrastructure with new fuel-efficiency regulations. FAME II which was announced by the Government of India in March 2019 aims to promote the EV sector in India through different incentives for both the supply and the demand side. However, as currently framed these initiatives by the government have no mention of bidirectional charging of EVs. Inclusion of incentives that can make V2X attractive for potential stakeholders would go a long way in developing V2X in the country. The different initiatives that can be considered here are,

- Introducing V2X as a priority sector within the EV ecosystem.
- Creation of a body at the central level for coordinating the regulation and standards necessary for V2X applications. As V2X requires close cooperation between the automotive industry, the department of transportation and the electricity regulatory authorities a central body that can coordinate the efforts can prove to be valuable.
- Introduction of subsidies and grants for V2X hardware
- Focus on research and development and facilitation of pilot projects for different V2X applications.
- Promotion of demand response.
- Promotion of local energy management solutions, which can help in development of the residential energy management sector in India.

In the Indian Budget 2022, infrastructure status was provided to energy storage systems. This would provide the stakeholders in this sector access to credit and long-term funds on better terms[67]. This would provide a much-needed impetus to the energy storage sector, which can also lead to increased penetration of the renewable energy sector as well. A similar infrastructure status if provided for EV charging station and for V2X hardware can go a long way in development of the EV ecosystem.

5.2.2 State EV Policies

Majority states in India have also developed EV policies for development of the EV ecosystem in the state. As most Indian states generally have a lower number of EVs, the focus of these state policies is largely to incentivize its populace to purchase EVs. Some state policies have also incorporated charging infrastructure. There is generally a lack of the charging management solutions in these state policies. Regarding, bidirectional

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[67] ETEnergyWorld, “Infrastructure status presents opportunities for green data centres”, March 2022. https://energy.economictimes.indiatimes.com/news/power/infrastructure-status-presents-opportunities-for-green-data-centres/90274873

charging, only three states have made a tangential comment on V2G. Hence for development of V2X ecosystem, the state policies need to include the following initiatives.

- Provide special financial assistance for establishing V2G capable charging station
- Create an environment such that there is increased collaboration between charge point operators and the DISCOMs, in order to establish well designed V2G charging stations.
- Mandating the state electricity regulatory authority for designing appropriate tariffs for V2X implementation.
- Mandate the state electricity regulatory authority to also design ToU tariffs for residential customers.
- Subsidize the cost of procurement of smart charging software, communication infrastructure and metering equipment.
- Allocating a minimum requirement of renewable energy certificates for EV charging stations. With the upcoming Carbon credit trading scheme, maximum carbon emissions by a PCS can be similarly capped.
- Allocation of funds for R&D in V2X projects.
- Awareness programs for spreading of benefits of V2X applications.

5.3 Modifications in technical standards

Besides modification in the grid code, the technical standards currently in the Indian EV ecosystem needs to be further fleshed out to enable V2X. The standards in the current Indian EV ecosystem are:

Standard	Title
IS 17017 (Part 1): 2018	Electric Vehicle Conductive Charging System Part 1: General Requirements

IS 17017 (Part 2/Sec 1): 2020	Electric Vehicle Conductive Charging System Part 2: Plugs, Socket-Outlets, Vehicle Connectors, and Vehicle Inlets Section 1: General requirements
IS 17017 (Part 2/Sec 2): 2020	Electric Vehicle Conductive Charging System Part 2: Plugs, Socket – Outlets, Vehicle Connectors and Vehicle Inlets Section 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories
IS 17017 (Part 2/Sec 3): 2020	Electric Vehicle Conductive Charging System Part 2 Plugs, Socket — Outlets, Vehicle Connectors and Vehicle Inlets Section 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers
BIS IS 17017 (PART 21 / SEC 1): 2019	Electric Vehicle Conductive Charging System Part 21 Electromagnetic Compatibility requirement Section 1: On board chargers
BIS IS 17017 (PART 21 / SEC 2): 2019	Electric Vehicle Conductive Charging System Part 21 Electromagnetic Compatibility requirement Section 2: Off board chargers
IS 17017 (Part 25): 2021	Electric Vehicle Conductive Charging System Part 25 D.C. EV Supply Equipment where Protection Relies on Electrical Separation

In addition to the above, the following communication standards have also been published.

Standard	**Title**
IS/ISO 15118-1:2013	Road vehicles - Vehicle to grid communication interface - Part 1: General information and use case definition

IS/ISO 15118-2:2014	Road vehicles -- Vehicle-to-Grid Communication Interface -- Part 2: Network and application protocol requirements
IS/ISO 15118-3:2015	Road vehicles -- Vehicle to grid communication interface -- Part 3: Physical and data link layer requirements
IS/ISO 15118-4:2018	Road vehicles - Vehicle to grid communication interface - Part 4: Network and application protocol conformance test
IS/ISO 15118-5:2018	Road vehicles - Vehicles to grid communication interface - Part 5: Physical and data link layer conformance tests
IS/ISO 15118-8:2020	Road vehicles - Vehicle to grid communication interface - Part 8: Physical layer and data link layer requirements for wireless communication

The IS/ISO 15118 set of standards deal with the communication between the EVSE and the EV and is crucial for V2X implementation. However, the set of IS/ISO 15118 standards in India is not yet complete. The ISO 15118 standard transmits data from one entity to another using the OSI layers. Open Systems Interconnection (OSI) is one of the well-known architecture in the communication domain. It is a 7 layer architecture with each layer having specific functionality to perform. The 7 layers of the OSI architecture are shown in Figure 5:7.

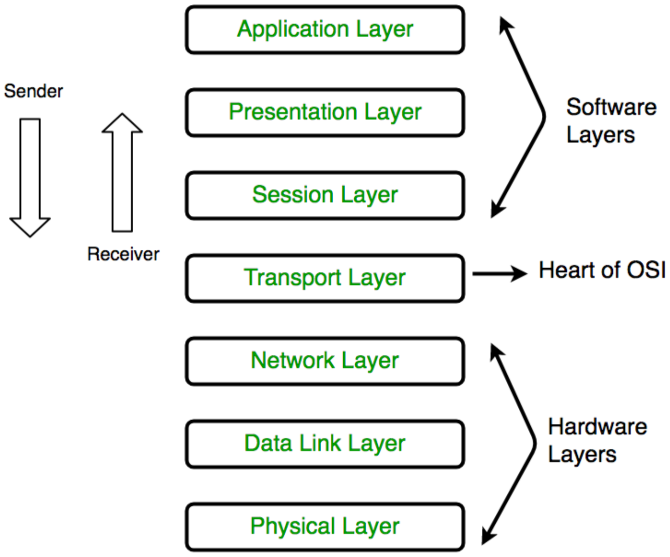

Figure 5:7: Layers of the OSI architecture[68]

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[68] OSI Full Form,Accessed on July,23, https://www.geeksforgeeks.org/osi-full-form/

The ISO 15118 Part 20 which was recently launched in 2022 titled 'Road vehicles — Vehicle to grid communication interface — Part 20: 2nd generation network layer and application layer requirements' defines the communication messages and sequence requirements for bidirectional power transfer. So, for India too this standard needs to be adopted to enable OEMs to manufacture V2X capable CCS compatible hardware in compliance with the standard.

As of 2022, CHAdeMO is the only charging standard that is capable of bidirectional charging. But as the popularity and the future growth of CCS chargers in India is expected to be much higher compared to CHAdeMO, so V2X capable CCS hardware would be needed to be developed. With the launch of ISO 15118 Part 20 in the global market, CCS V2X capable hardware are currently in the works with different OEMs participating, such as the Wallbox Quasar 2. So, a similar approach can also be followed in the Indian EV ecosystem.

Section B:

Techno-economic analysis of V2X implementation in India

Chapter 6. Impact of EV load growth in Indian Grid

6.1 Introduction

The development of EV technology is regarded as a crucial step in rapidly reducing the global carbon emissions and dependency on expensive crude oil imports for the transportation industry. Several studies have already been conducted to determine if future power networks will have the necessary infrastructure and power generation capacity to accommodate significant penetrations of EVs[69,70]. The mentioned studies concluded that existing and planned generation capacities should, for the most part, be adequate to handle the increased demand for EVs. However, this might not be the case if this increased demand faces a deficit during the peak load points. With the introduction of EVs, new consumer demand patterns will emerge, and significant EV penetrations could have a negative impact on the network due to congestion, voltage deviation, power quality related aspects, raising the possibility of significant simultaneous electricity demand. Since distribution networks are often radial by nature, adding relatively large-scale loads may have a more significant impact than on meshed networks. This study examines the potential impacts of EV integration on existing distribution networks, with an emphasis on the residential LV networks.

6.2 Impact of EVs on the distribution system

The distribution networks can introduce several technical issues driven primarily by unique charging profile of the EVs. Typically, un-controlled/un-coordinated, controlled/coordinated, delayed, and off-peak charging are some of the charging strategies used to coordinate the time and frequency with which EVs are charged.In the uncoordinated charging strategy, the batteries of the EVs either begin charging right away once they get plugged in after arriving at the destination charging (often during peak hours)

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[69] Kintner-Meyer, Michael & Schneider, Kevin & Pratt, Robert. (2007). Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional US Power Grids: Part 1: Technical Analysis.

[70] Stanton W. Hadley, Alexandra A. Tsvetkova, Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation, The Electricity Journal, Volume 22, Issue 10, 2009, Pages 56-68, ISSN 1040-6190, https://doi.org/10.1016/j.tej.2009.10.011.

or after a user-adjustable fixed start delay. In case of uncoordinated dumb charging, coincidence of the EV charging load peak with the base load evening peak can result in breaching of the transformer/feeder limits. Uncoordinated charging has several negative impacts, including overloading, increased losses, voltage unbalance, increased overall costs, etc.

By charging EVs during off-peak periods through coordinated charging, EV hosting capacity of the existing distribution system can be increased. In this study, coordinated charging has been considered based on the available number of chargers for charging. A section of the electric vehicles are charged during the night, i.e. off-peak hours such that the aggregted load on the system does not lead to congestion in the network.

6.3 EV Modelling

This section describes the modelling features and considerations to generate realistic time-series EV load profiles. It also describes the key factors and approaches to develop realistic EV models for this study. The EV demand is influenced by various factors including driver behaviour, charger rating, drive cycle etc. The other factors that need to be defined for an EV demand model are as mentioned below:

- Plug-in and Plug-out time – The most important parameters used to describe an EV charging event are the plug-in time and the plug-out time, which indicates the timeframe of EV charging.
- Daily Charging Times – This is one of the most important features for modelling EV charging demand. Since users might consider charging EVs multiple times during the day (e.g., after each trip), following plug-ins (i.e., more than one) should also be considered while modelling the EVs.
- Types of EV Chargers – The actual EV charging demand is determined by the type and rating of the EV charger. There are typically two EV charger models in the market for residential charging: Level 1 and Level 2. Voltage standards pertaining to the charger models vary from country to country, and so does the total EV demand. In Australia, for example, Level 1 (16A, 230V) and Level 2 (32A, 230V) demand roughly 3.3 kW and 7.36 kW, respectively. Similarly in India, the

predominant rated capacity of chargers include 3.3 kW, 7 kW and 11 kW for AC charging and 50 kW for DC charging[71].

- Battery Size – This is another critical parameter that affects EV charging profiles, mainly the charging duration. The battery size can be categorized as short-range (Less than 10kWh), medium-range (10 kWh – 25 kWh), long-range (25 kWh – 35 kWh), and extra-long range (more than 35 kWh).
- Vehicle type – Each vehicle type has its own trait of energy consumption. For example, the PHEV can still be used after the battery is discharged completely, but that same is not valid for the BEVs. The PHEVs have a smaller battery compared to BEVs, and the charging duration of BEVs is longer than that of PHEVs.
- EV Penetration – Penetration is defined as the percentage of houses with a single EV. The maximum penetration considered in this study is 100%, i.e. one EV for every house.

6.4 Distribution Test System

A real life Indian LV distribution system has been considered for conducting the simulation studies. The details of the test system, containing 450 domestic houses, are given in Table 6.1.

Table 6.1. Test system parameters

Component	Description
Domestic Houses	450
Transformers	11/ 0.4 kV (12 nos.)
System Capacity	5.17 MVA
Maximum number of EVs	450

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[71] Few EV models available in India also have DC charging capability as high as 270 kW.

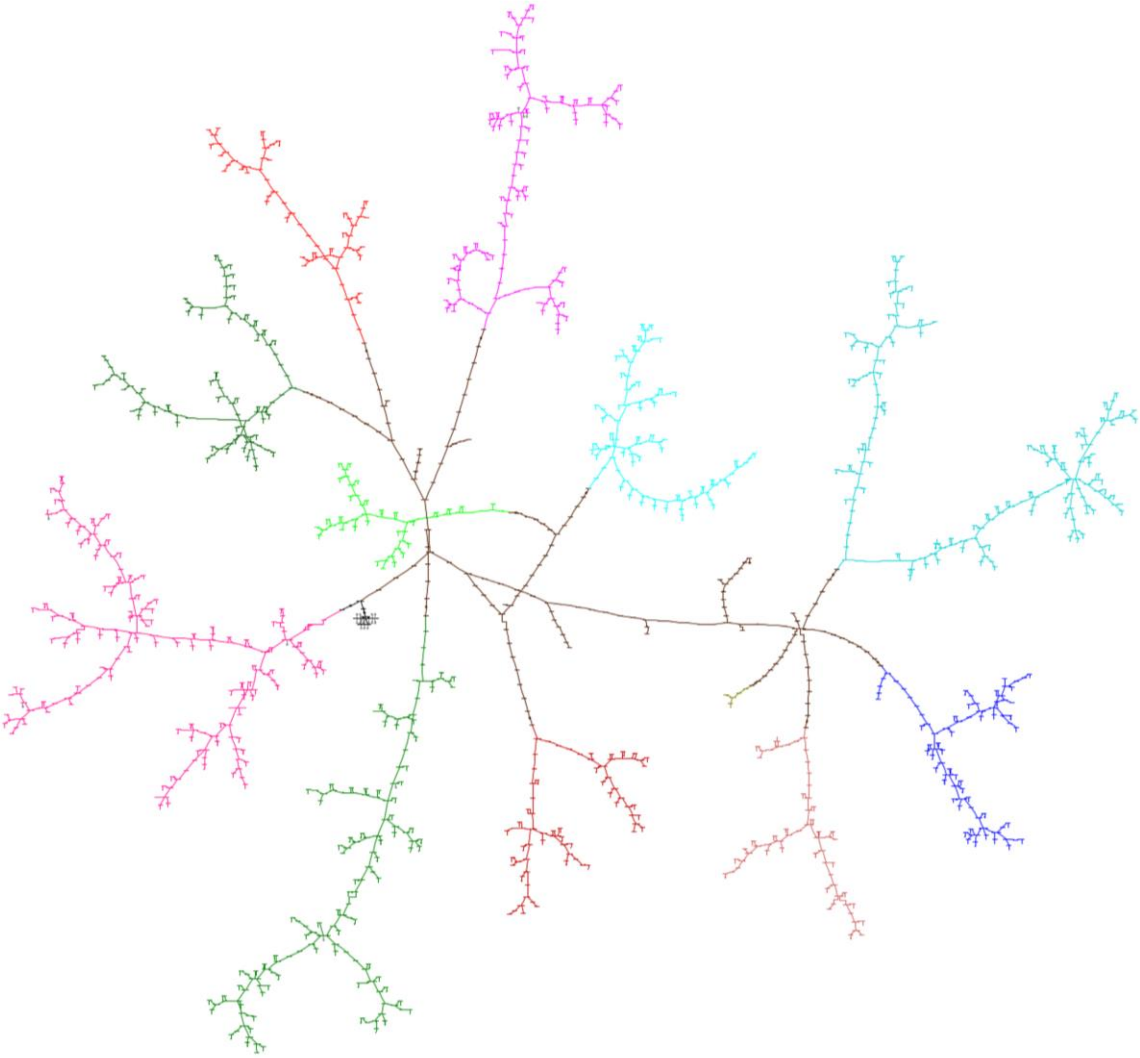

Figure 6:1: Network diagram of the distribution system

Figure 6:1 shows the network diagram of the system. For the selected network, a peak load of 2.59 MW is observed at 11:00 PM. For this network, Figure 6:2 shows the loading of the LV distribution system under the base case. All the transformer loadings are below 100% before integrating EVs to the network, as shown in Figure 6:3.

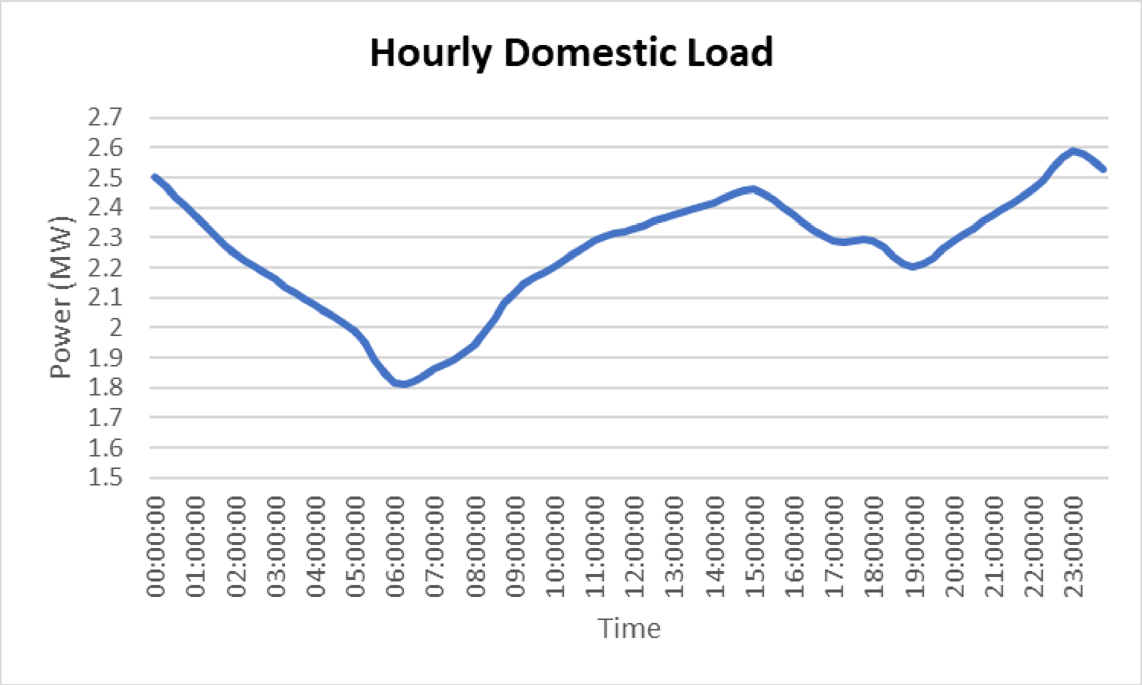

Figure 6:2. Feeder loading under base case[72]

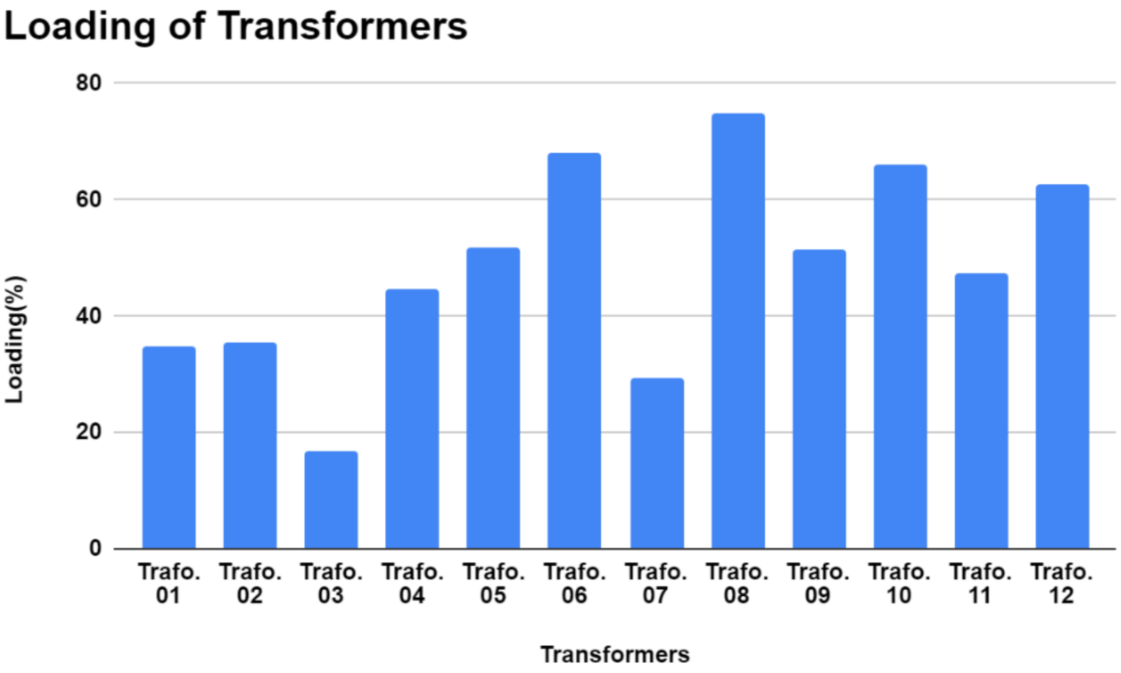

Figure 6:3. Transformer loadings in the base case

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[72] Probal Ghosh, Vinay Kumar Saini," Electric Vehicle Charging Patterns and Impact on DISCOMs", Shakti Sustainable Energy Foundation,2022

EVs in different penetration levels have been integrated to the model, and analysis is performed for a period of 24 hours, while some of the static analysis has been conducted on annual basis. It has been assumed that EVs when connected to the charging station, will have initial state-of-charge (SoC) ranging from 20% to 30%.

6.4.1 Load Modelling

The accurate modelling of system load is one of the critical components in analysing the impacts of EV integration on the distribution network. In this study, the loads have been modelled as 3 phase voltage dependent loads as given in Eq. 1 and Eq. 2.

$$P_{load} = P_0 \left(\frac{|v|}{v_0} \right) \qquad \text{Eq. 1}$$

$$Q_{load} = P_0 \tan(\phi_0) \left(\frac{|v|}{v_0} \right) \qquad \text{Eq. 2}$$

Here, P_0 is the power drawn by the load, when the voltage at the load terminals is 1 p.u. and ϕ_0 is the power factor of the load.

6.5 Uncoordinated Charging

The EV charging scheduling is formulated with the objective of minimising the total electricity cost incurred by the consumer, i.e. the EVs are being charged primarily during the night hours when the cost of electricity is lower. Two cases have been studied in this section –

- Case 1 – Impact of 3-phase domestic EV charging
- Case 2 – Impact of 1-phase domestic EV charging

6.5.1 Case 1 – Impact of 3-phase domestic EV charging

In this case, the households are considered to have a 3-phase 7 kW charger for a 4-wheeler with a 30-kWh battery. Five levels of EV penetration are considered to analyse the impact of varying levels of EV penetration. It has been assumed that EV owners tend to charge the EV as soon as they reach home after their daily work. Typically, EVs get connected to the charger in the peak evening hours. The arrival behaviour of EVs coming to the house and connecting to the charger is shown in Figure 6:4.

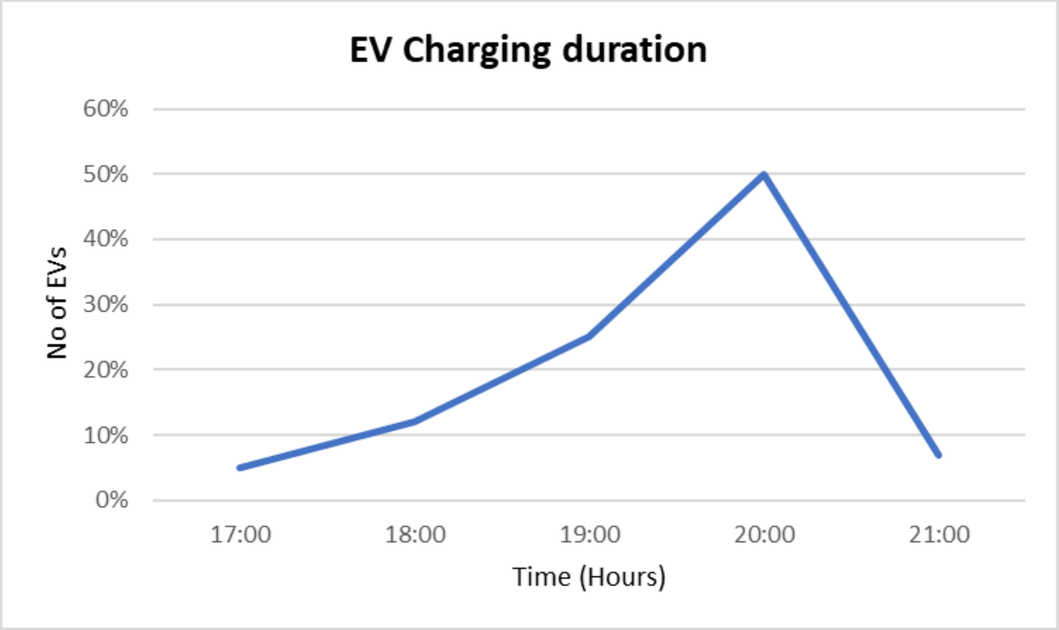

Figure 6:4. EV charging behaviour[73]

Around 50% of the EVs arrive at their residences at 8 PM and connect to the charger for charging. Each charger takes around 4 hours to fully charge the battery. The plug-in times of the EVs is randomly selected between 5:00 PM to 9:00 PM.

6.5.2 Case 2 – Impact of 1-phase domestic charging analysis

In this case, two separate scenarios have been analysed. In the first scenario, a higher share of the single-phase chargers is connected to a single-phase of the network (assumed here to be Phase A). In the second scenario, the chargers are considered to be equally distributed among the three phases. For this scenario, it is assumed that the EV owned by the occupant is a 4-wheeler with a 15-kWh battery. Three levels of EV penetration are considered to analyse its corresponding impacts. The phase unbalances in both the case studies are provided in Table 6.2.

Table 6.2. Percentage of EVs connected to each of the phases

Scenarios	Phase A	Phase B	Phase C
Case study-2 (a)	80%	10%	10%
Case study-2 (b)	34%	33%	33%

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[73] Probal Ghosh, Vinay Kumar Saini," Electric Vehicle Charging Patterns and Impact on DISCOMs", Shakti Sustainable Energy Foundation,2022

6.6 Results: Uncoordinated Charging

6.6.1 Case Study 1 – Impact of 3-phase domestic charging analysis

For different penetration levels, the power demand due to charging EVs is shown in Figure 6:5. It can be observed from Figure 6:6 that few of the transformers are overloaded at the substation as the penetration level increases. One LV distribution transformer has asset utilisation problems at just 20% EV penetration where the transformer hits its 100% loading limit, while higher penetration level results in more transformers breaching their capacity limit. Therefore the impact magnifies further as EV penetration increases, with five transformers overloaded at 100% EV penetration.

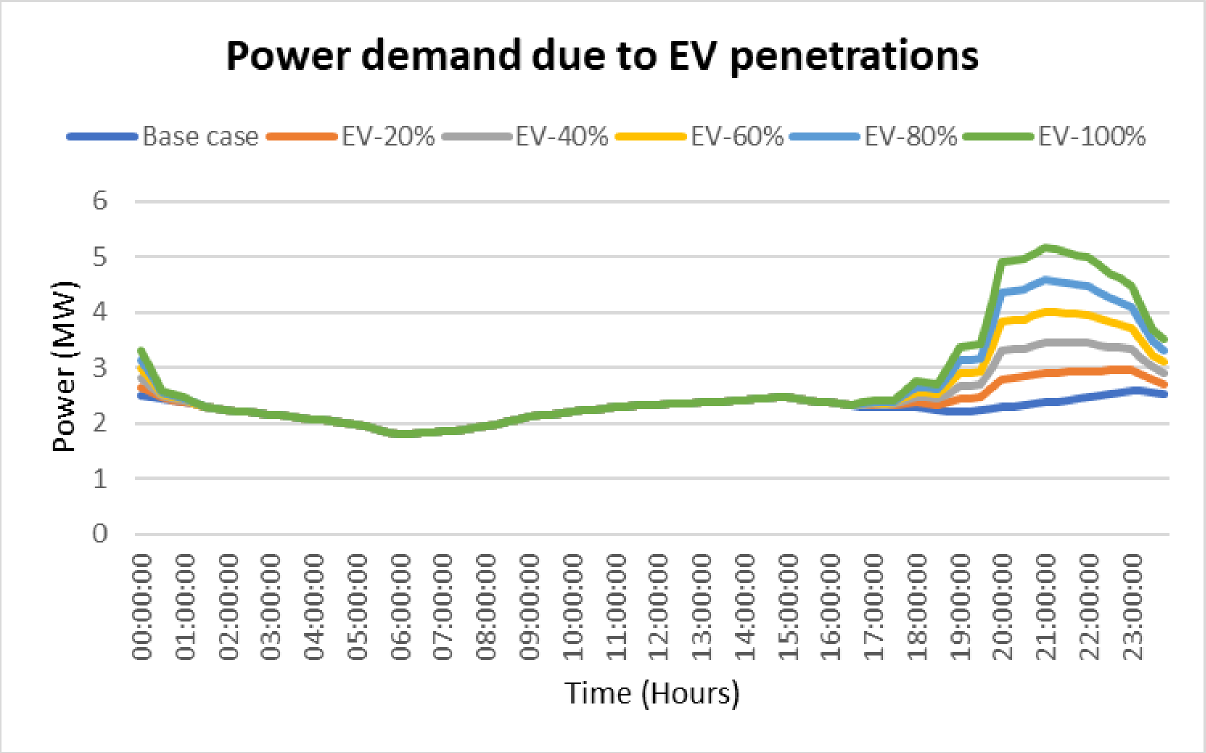


Figure 6:5. Power demand due to EV 3-phase charging

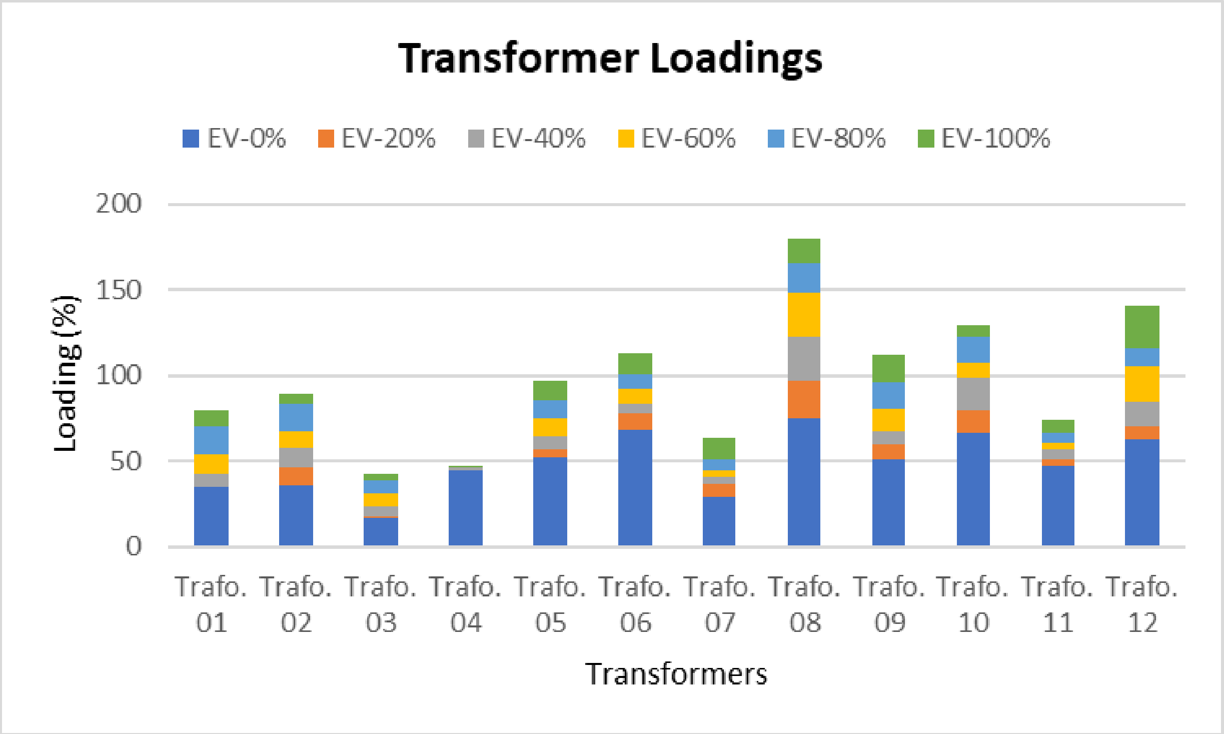


Figure 6:6. Transformer loading at the substation due to EV 3-phase charging

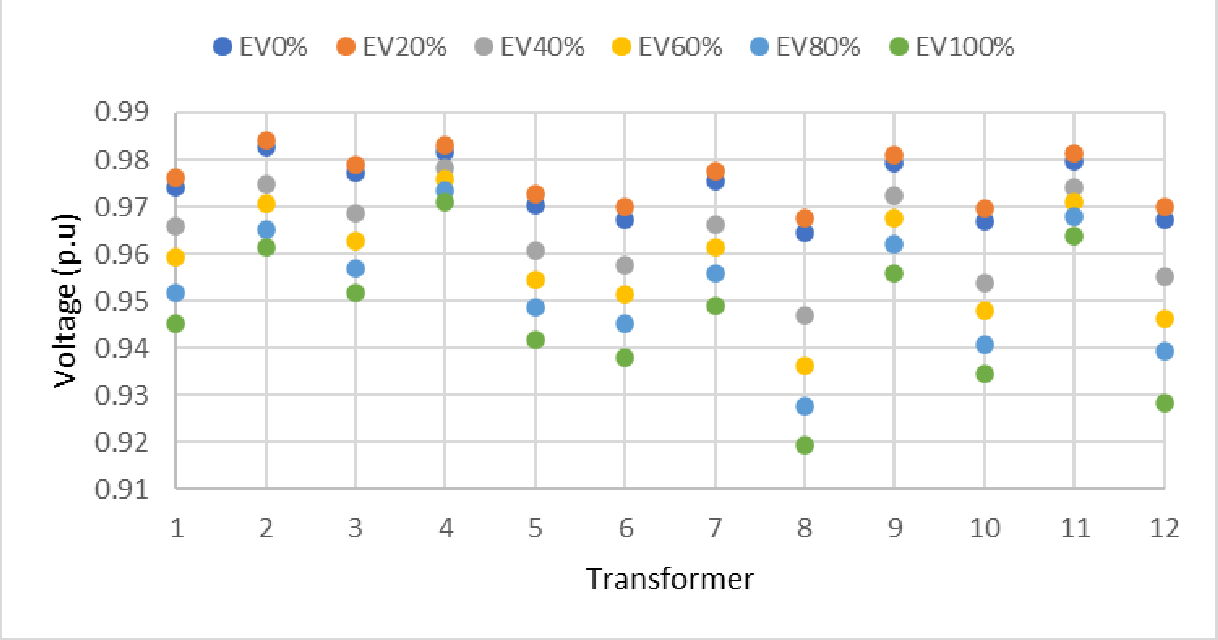


Figure 6:7. Transformer voltages at the substation due to EV 3-phase charging

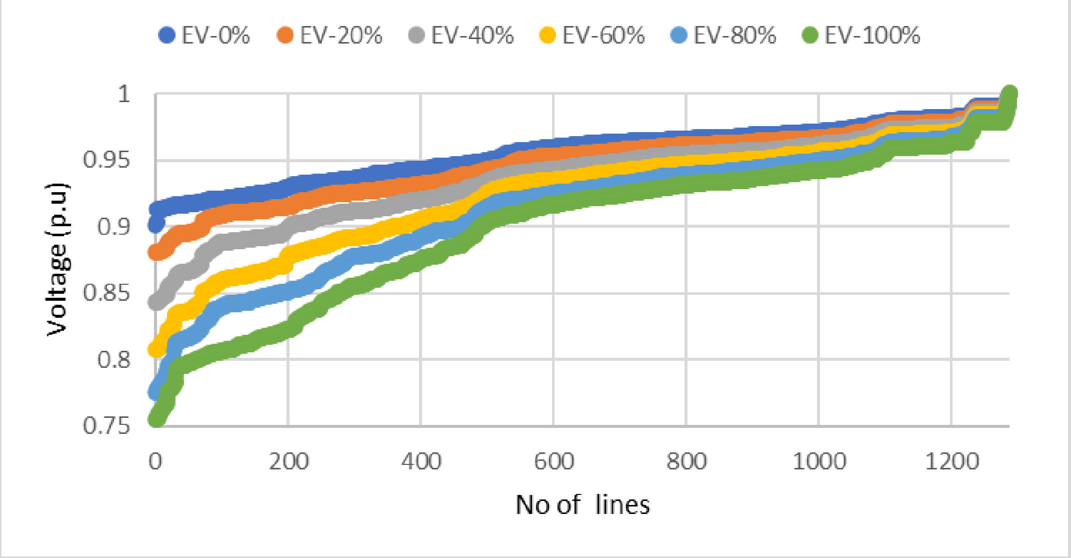


Figure 6:8. Line voltages for different penetration levels

The voltages at the substation decrease, as a higher number of EVs are connected, as shown in Figure 6:7. For 100% penetration of EVs, it can be observed that the voltage drops down to 0.92 p.u. There are approximately 500 feeder branches in the network whose voltage is less than 0.9 p.u. for 100% penetration, as shown in Figure 6:8. In this case, the minimum voltage on the feeder lines is 0.75 p.u. Customers experiencing the lower voltage profile pose a challenge at 20% EV penetration and beyond, with increased severity at 100% EV penetration.

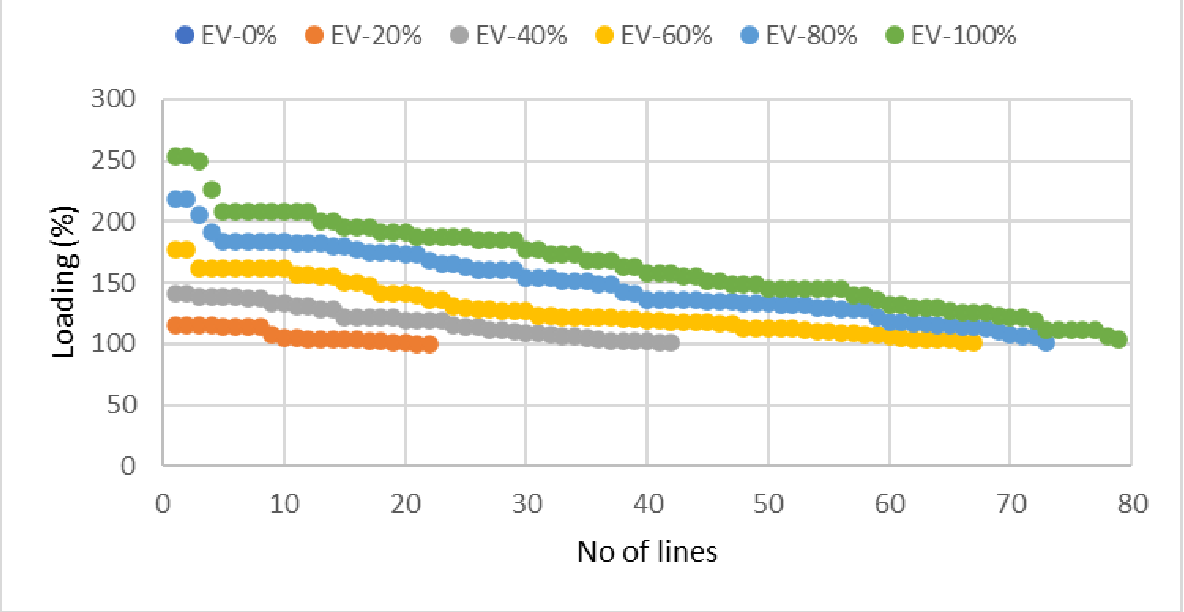
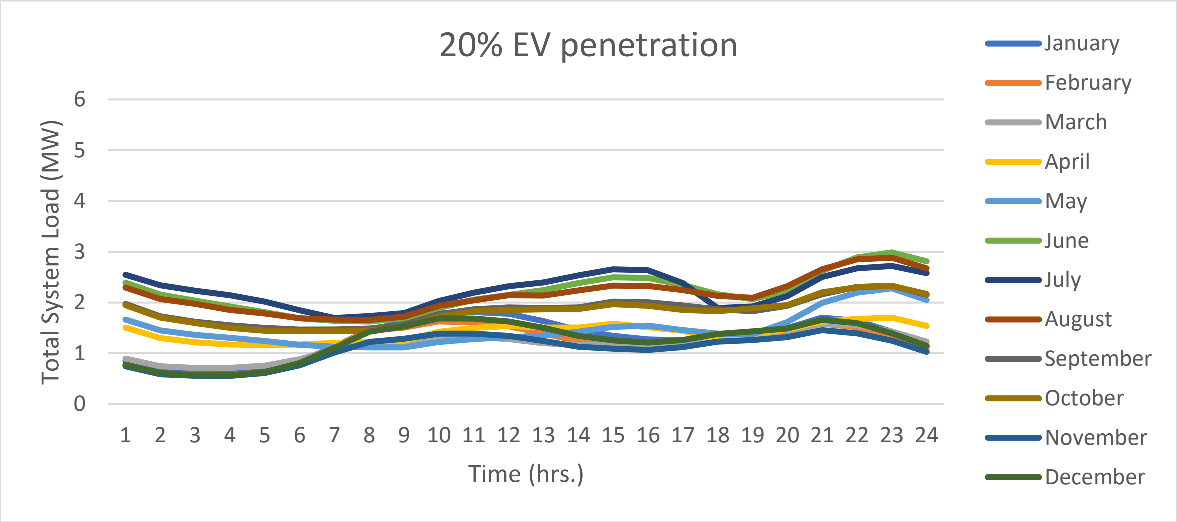


Figure 6:9. Line loadings for different penetration levels

Few of the lines in the network get overloaded due to increased EV penetration. Around 80 lines are overloaded under 100% EV penetration scenario, as shown in Figure 6:9.

The analysis has also been extended to account for the seasonal variations in the system demand. For this analysis, representative load curves have been considered for all the months of a year for Delhi State[74]. The resulting system load for different months of the year for different EV penetration scenarios is given in Figure 6:10, which shows that even for low penetration of 20%, the period of peak load is shifted to the night hours, especially during the summer months of May, June, July, August and September. With EV penetration of 40% or more, the peak load period can be seen to consistently occur during the night hours when most of the EVs will be charging, irrespective of the month of the year.



(a)

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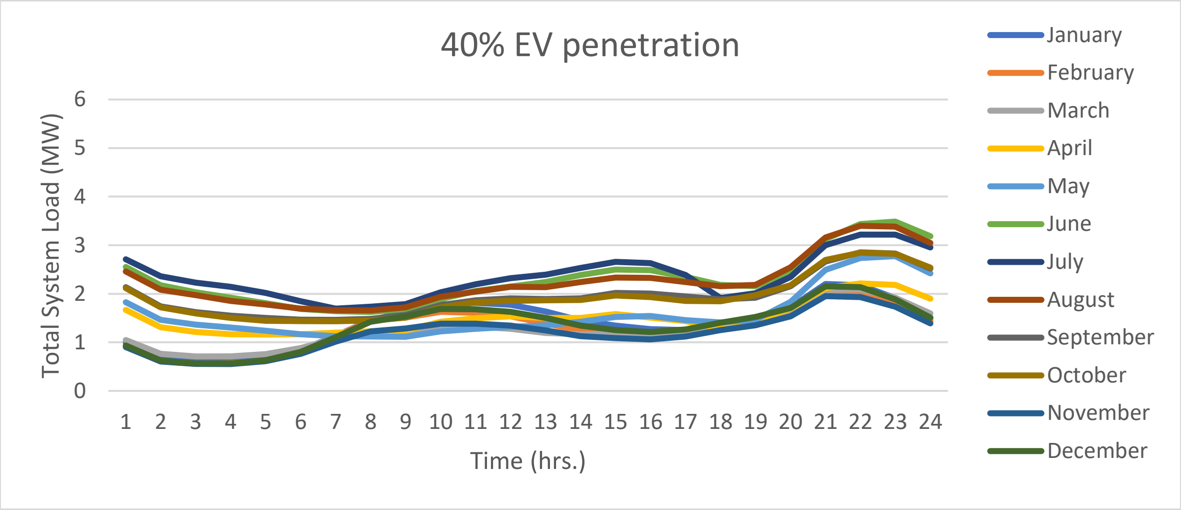
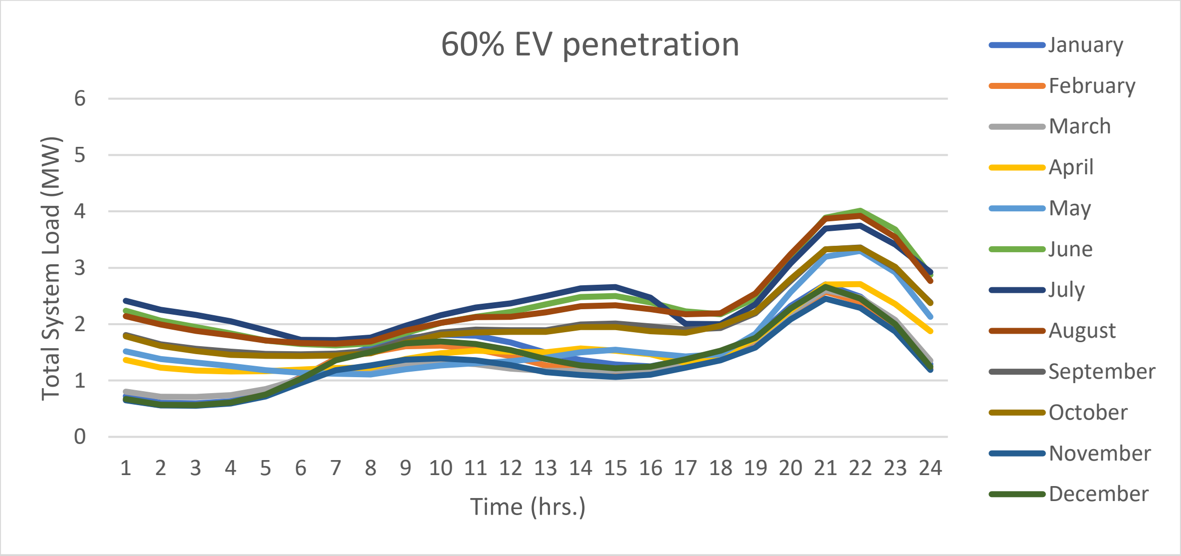
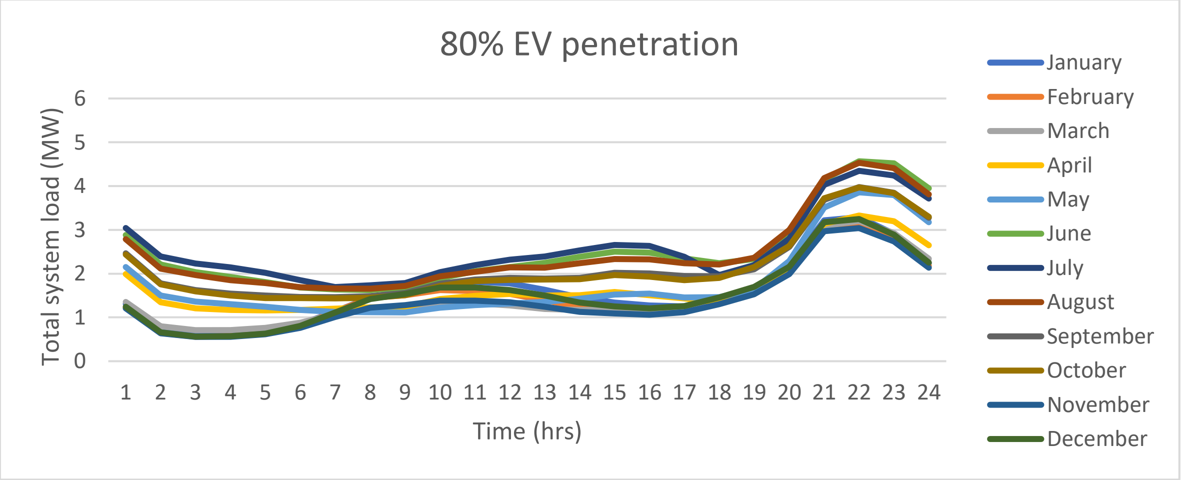
[74] State Load Dipatch Centre, Delhi, ‘Monthly Power Data ‘, Accessed: July, 2022, https://www.delhisldc.org/Redirect.aspx?Loc=1002


40% EV penetration
Total System Load (MW)
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hrs.)
January
February
March
April
May
June
July
August
September
October
November
December

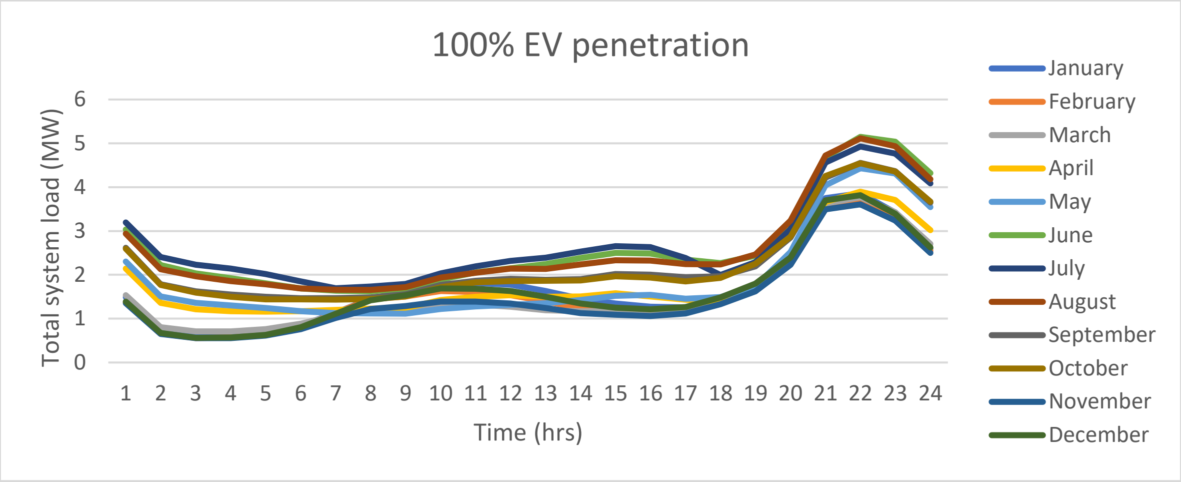
(b)


60% EV penetration
Total System Load (MW)
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hrs.)
January
February
March
April
May
June
July
August
September
October
November
December

(c)


80% EV penetration
Total system load (MW)
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (hrs)
January
February
March
April
May
June
July
August
September
October
November
December

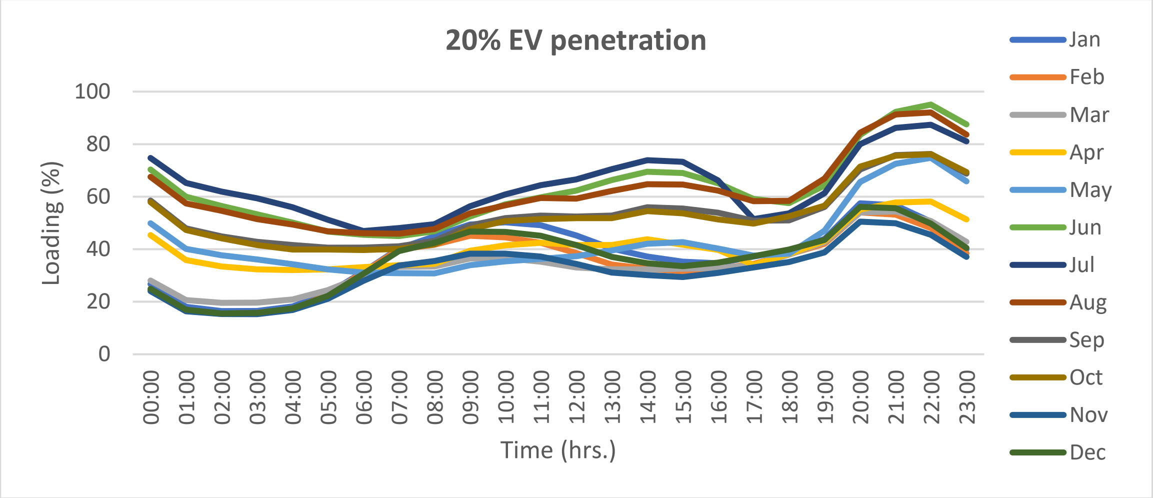
(d)



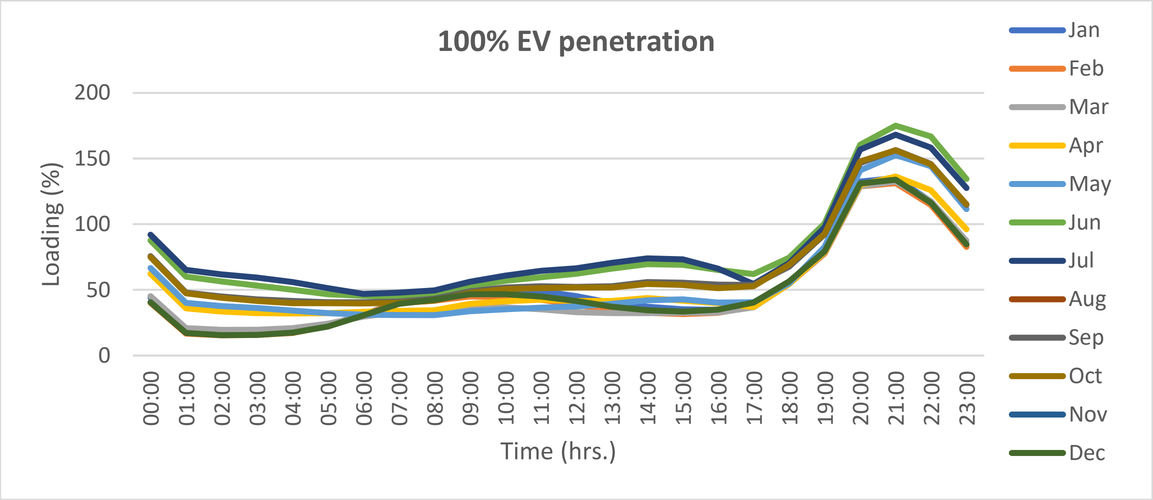
(e)

Figure 6:10: Total system load shown for different EV penetration levels for a) 20% EV penetration b) 40% EV penetration c) 60% EV penetration d) 80% EV penetration and e) 100% EV penetration

The increased EV loads also result in increased loading of the upstream transformers, potentially resulting in a voltage drop. The loading profile for the highest loaded transformer has been shown in Figure 6:11 for the 20% EV penetration scenario and 100% EV penetration scenario. Figure 6:12 shows the impact of 100% EV penetration on the transformer overloading, where each instance refers to its loading beyond its rated capacity for at least 1 hour in the day. As can be seen, the number of instances of overloading is higher during June, July, August and September across the transformers.



(a)



(b)

Figure 6:11: Percentage loading for the transformer with the maximum loading for (a) 20% EV penetration and (b) 100% EV penetration

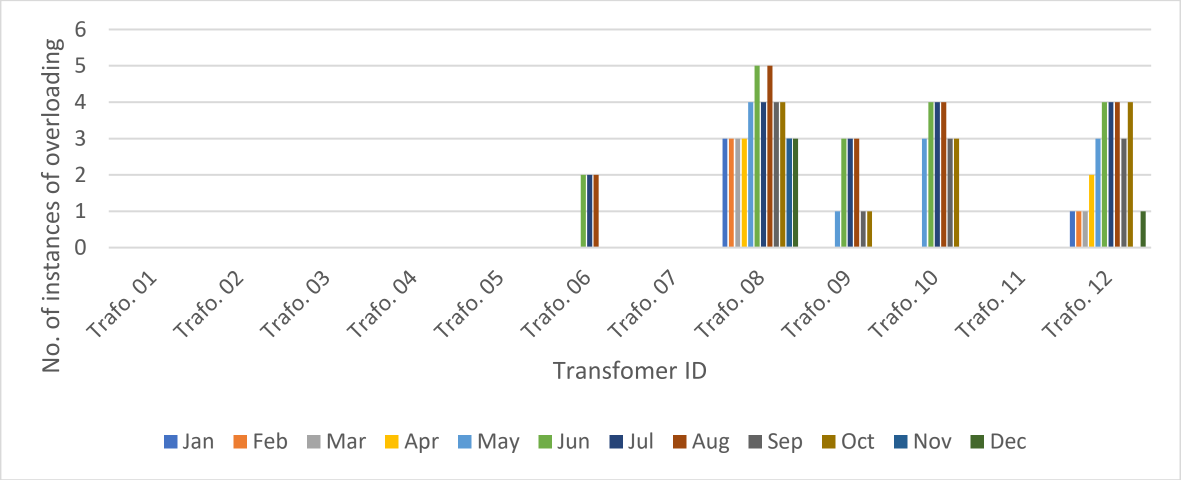
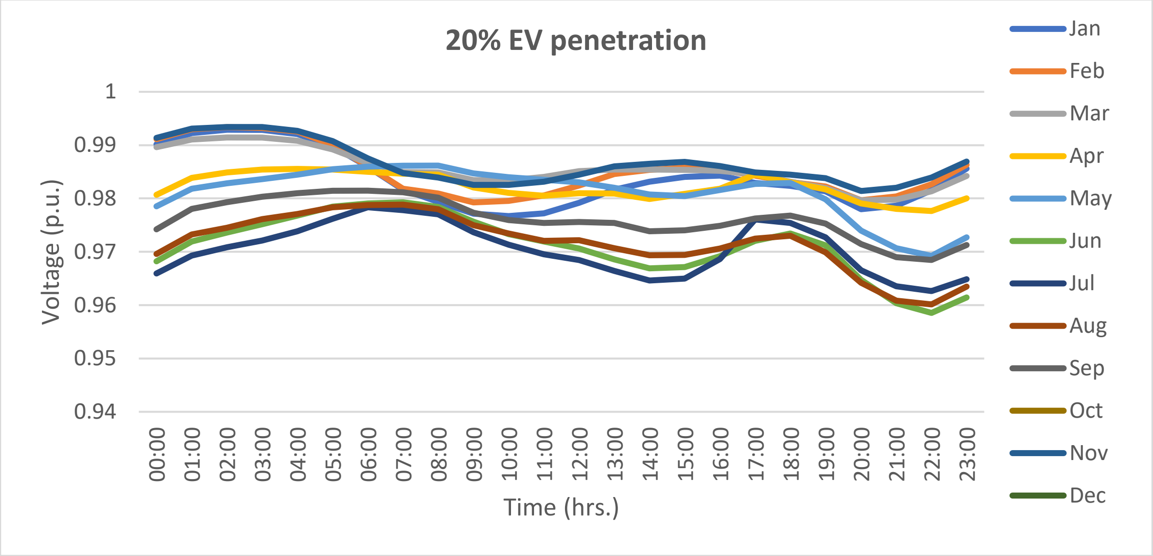
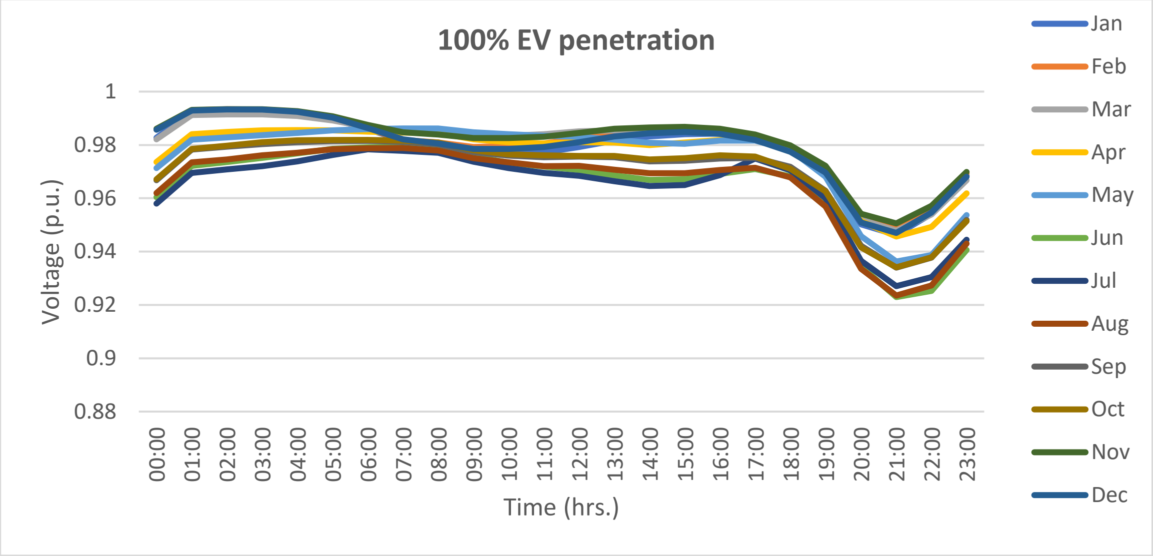


Figure 6:12: Number of instances where the transformers are loaded beyond their rated capacities for 100% EV penetration

Figure 6:13 shows the worst case voltage profile at the LV side of the transformer. It is evident from Figure 6:13(a) that for a 20% EV penetration case, the voltage drop due to EV charging is not significant as is the case for all the months, the voltage is maintained above 0.95 p.u. However, with the addition of more EVs into the system, the voltage at the transformer secondary drops to around 0.92 p.u. for a 100% EV penetration scenario. This can be attributed to the fact that, during these months, the base load was already high, thereby resulting in a reduction of the voltage during the night peak load periods under EV charging load during this period.



(a)



(b)

Figure 6:13: Voltage at the secondary terminal of the LV transformer shown for (a) 20% EV penetration and (b) 100% EV penetration

6.6.2 Case study 2 –Impact of 1-phase domestic charging

This case presents the impact of residential EV charging considering a 24-hour time-varying analysis of the distribution system for each penetration level, considering the worst-case and more realistic case scenarios. Three penetration levels are considered to analyse the impact of unbalance. Two different scenarios are simulated in this case, one with single phase unbalanced analysis and the other with single phase balanced analysis as described in Table 6.2.

The total power demand in the network due to EV 1-phase charging is shown in Figure 6:14.

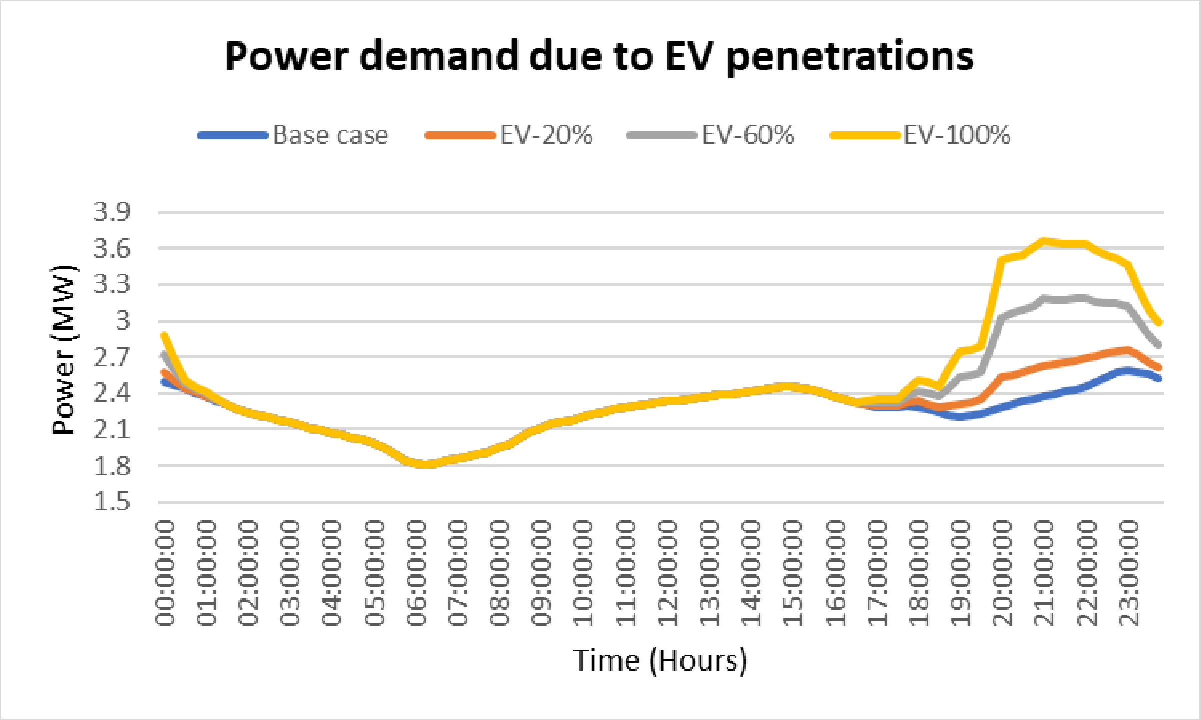
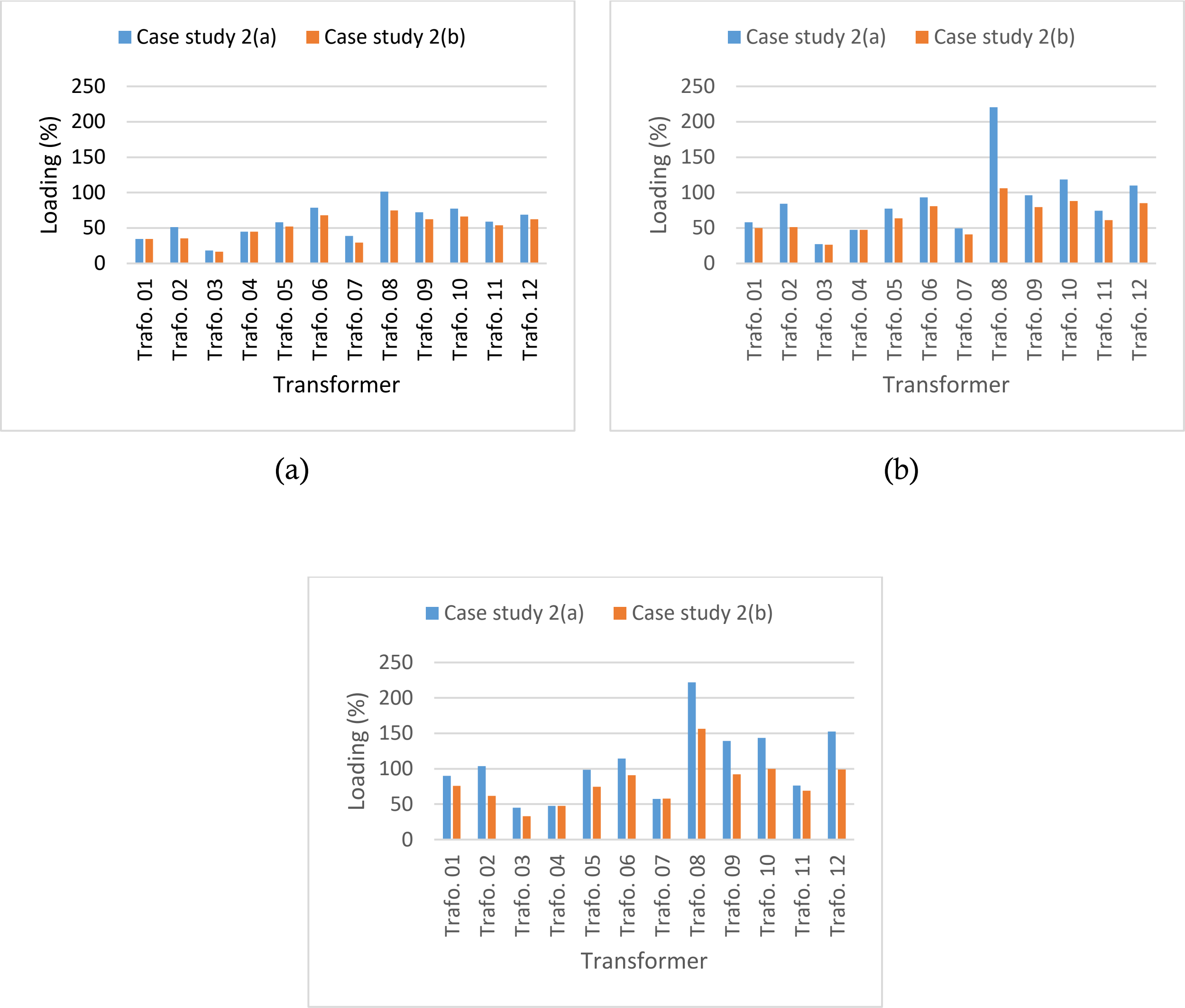


Figure 6:14. Power demand due to EV 1-phase charging

Transformer loadings for 20%, 60%, and 100% EV penetrations with single-phase unbalanced and balanced scenarios are shown in

Figure *6:15*. For 20% penetration, none of the transformers is overloaded, while for 60% penetration, three transformers are overloaded, and in 100% penetration level, seven transformers are overloaded in the unbalanced scenario. The transformer loadings are comparatively less in the balanced scenario when compared with the unbalanced scenario for the same penetration level.

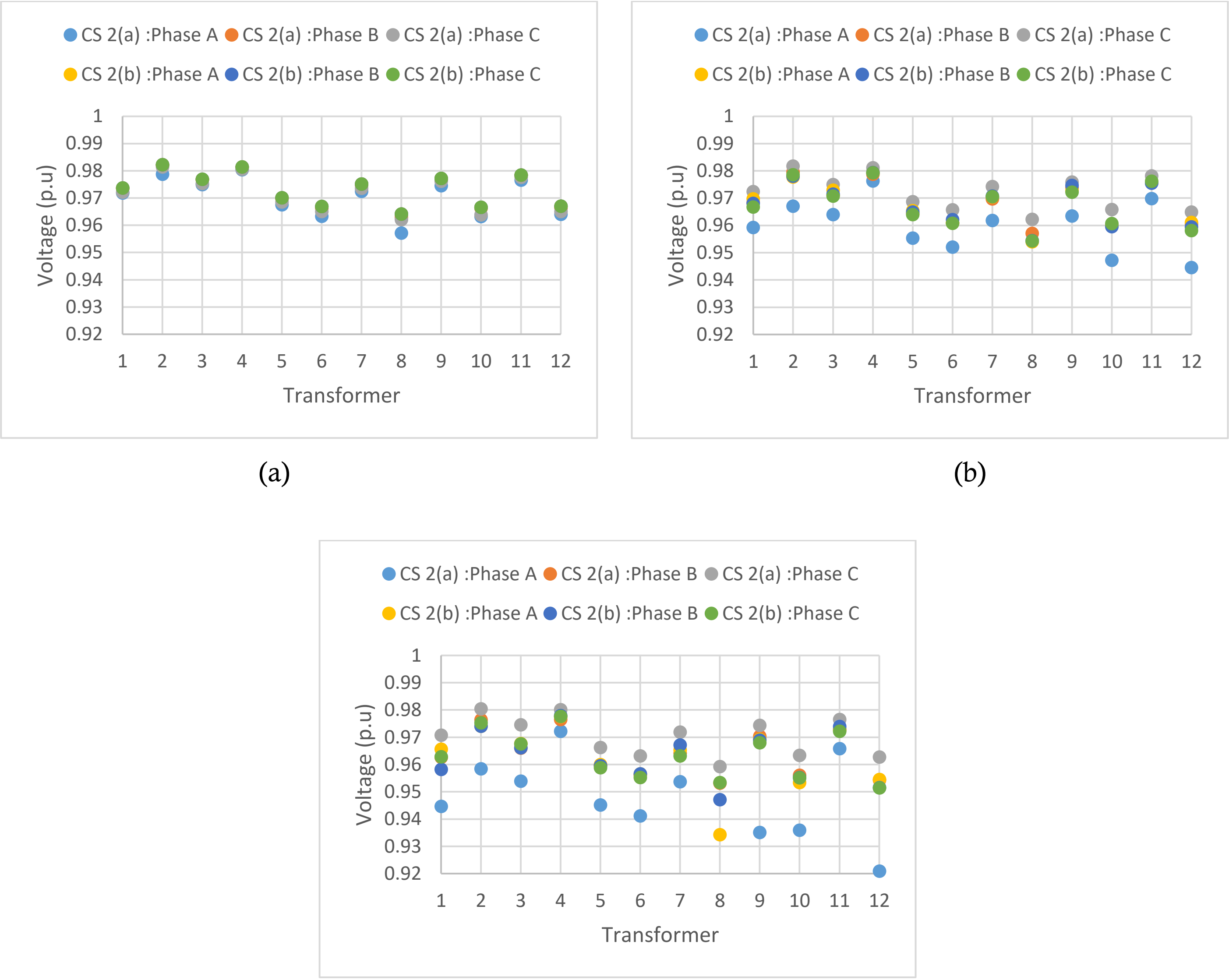


(a)

(b)

(c)

Figure 6:15. Transformer loading for (a) EV-20% (b) EV-60% (c) EV-100% penetration levels shown for Single phase unbalanced analysis (Case 2(A)) and single-phase balanced analysis (Case 2(B))



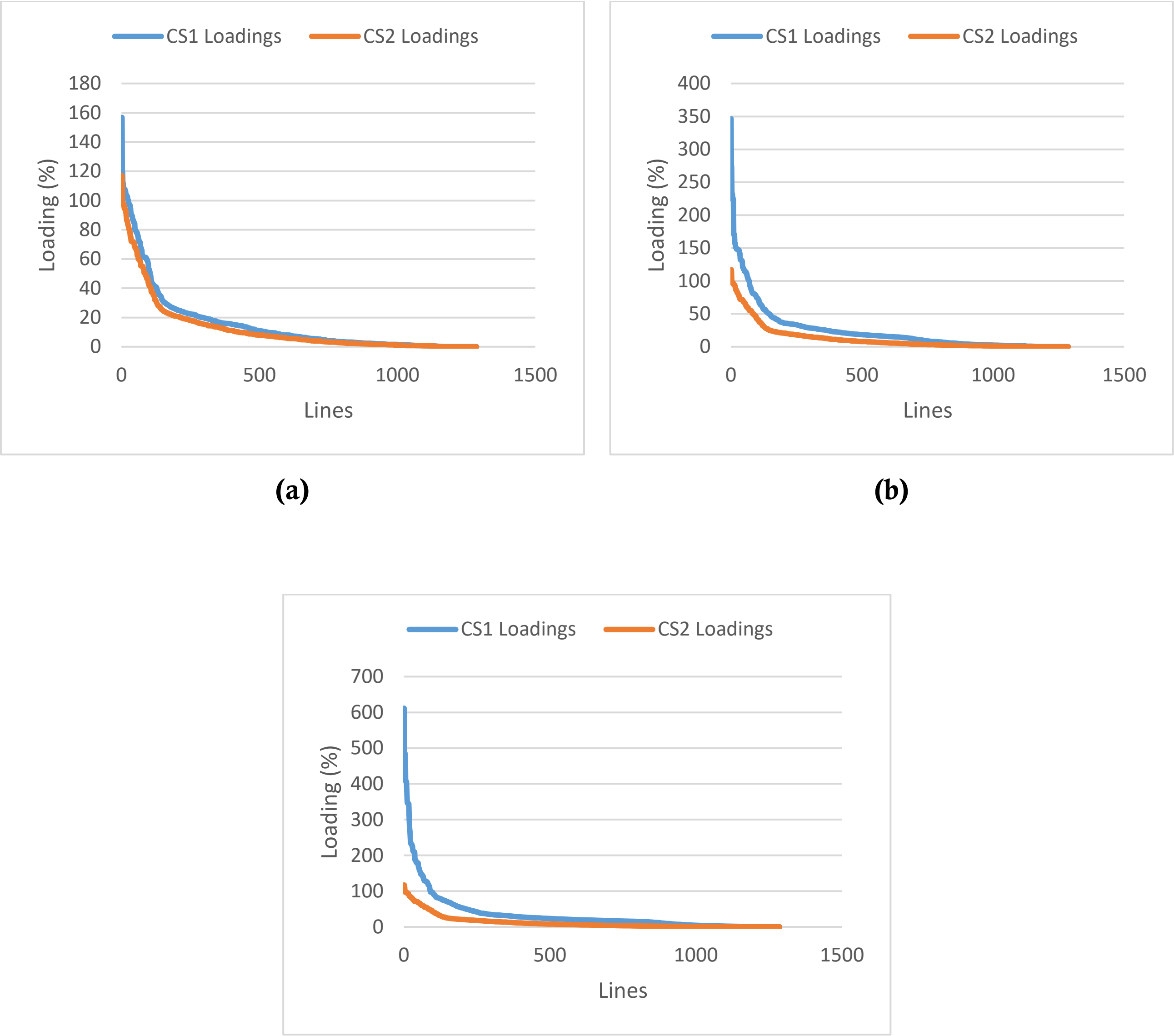
(a)

(b)

(c)

Figure 6:16. Transformer voltages for (a) EV-20% (b) EV-60% (c) EV-100% penetration levels

Transformer phase voltages for 20%, 60%, and 100% penetrations with single phase unbalanced and balanced scenarios are shown in Figure 6:16. None of the transformers is breaching their voltage limits for 20%, 60% and 100% penetration. Phase A voltages are the lowest among other phases as a higher number of EVs are connected to Phase A in the unbalanced scenario. The transformer voltages are comparatively less in magnitude in the unbalanced scenario compared to the balanced scenario for the same penetration level.

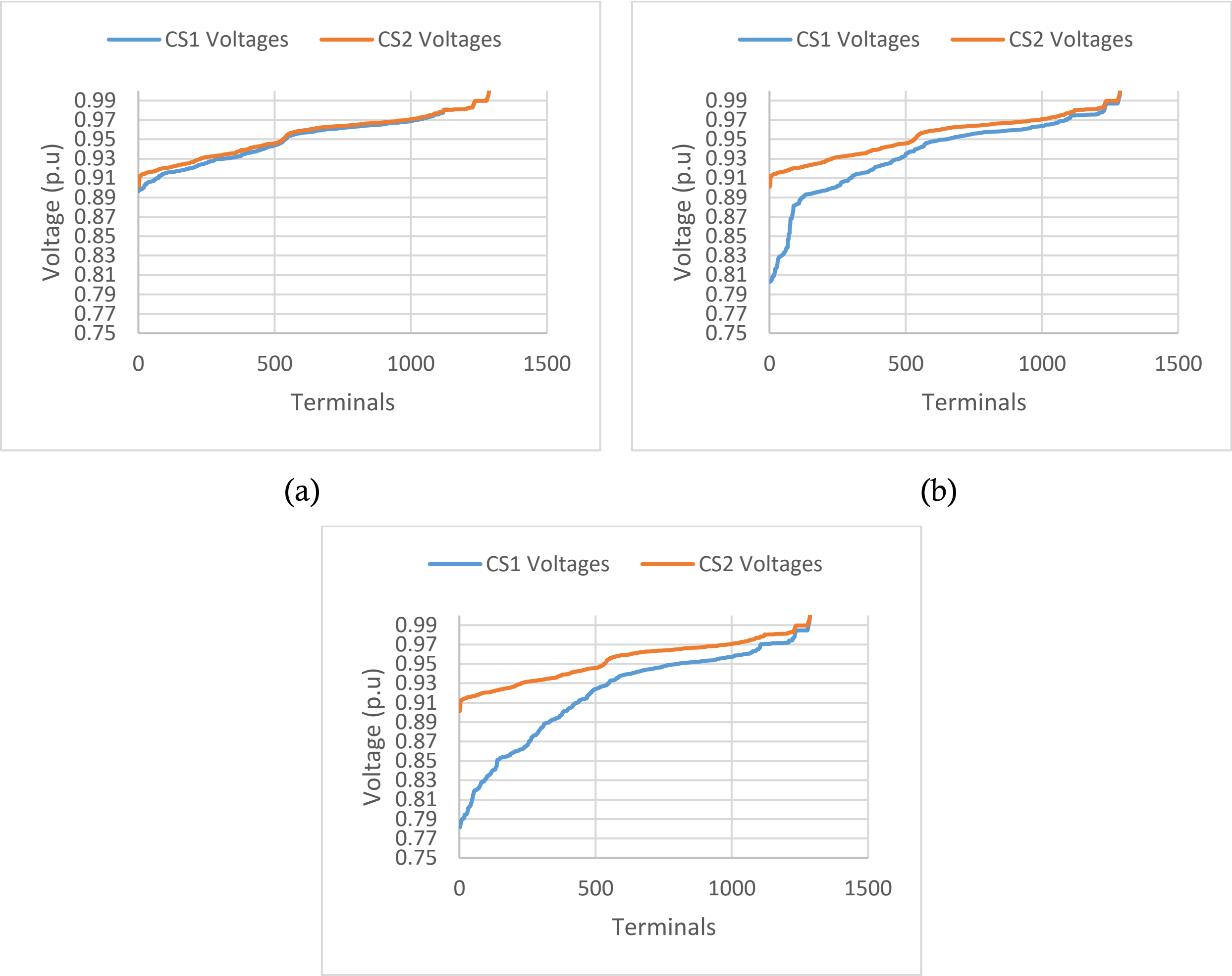


(a) **(b)**

(c)

Figure 6:17. Line loading for (a) EV-20% (b) EV-60% (c) EV-100% penetration levels

Line loadings for 20%, 60%, and 100% penetrations with single-phase unbalanced and balanced scenarios are shown in Figure 6:17. For 20%, 60% and 100% penetration, one of the lines are loaded to 160%, 350% and 610% respectively in unbalanced scenario. Line loadings are comparatively less in the balanced scenario when compared with the unbalanced scenario for the same penetration level.



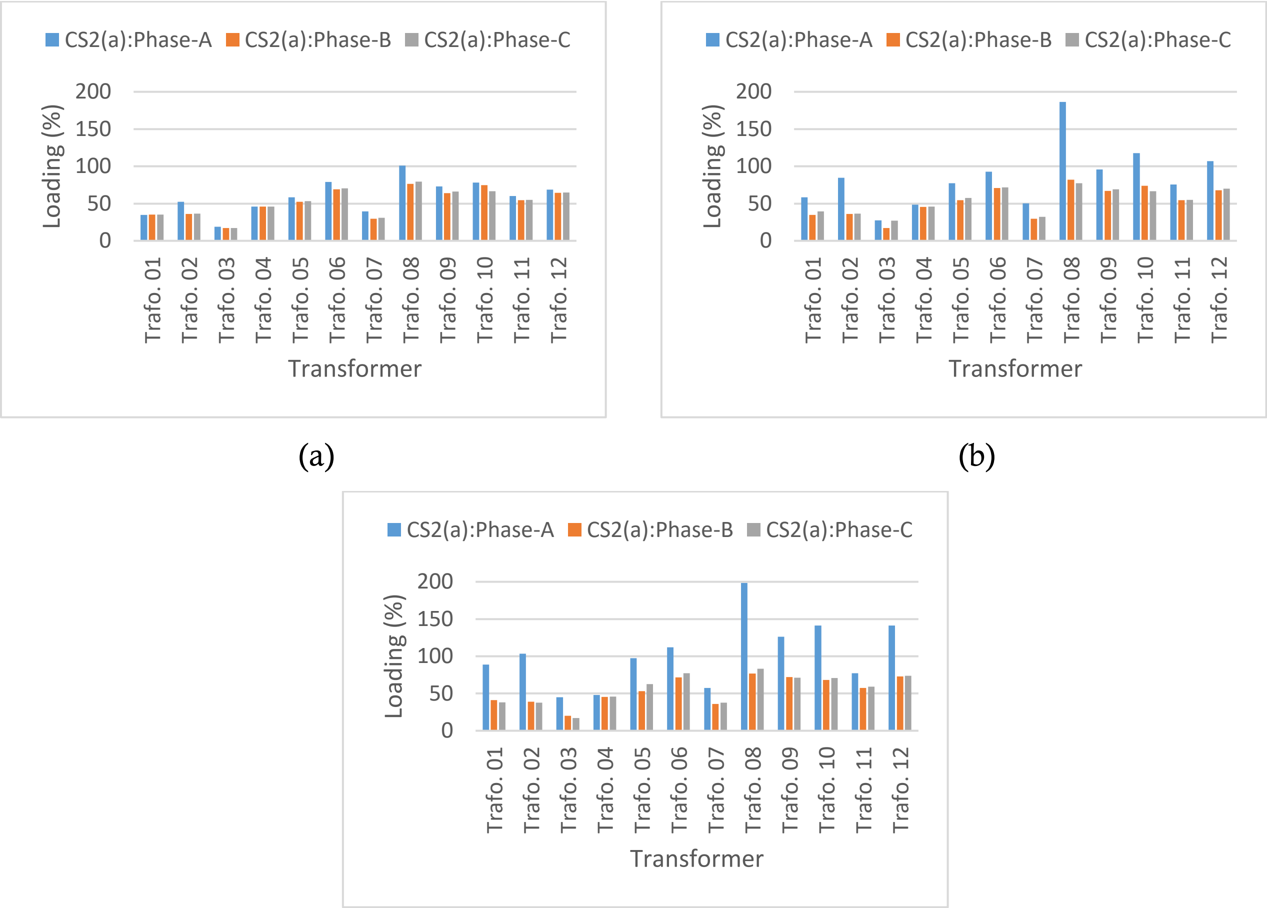
(a)

(b)

(c)

Figure 6:18. Terminal voltages for (a) EV-20% (b) EV-60% (c) EV-100% penetration levels

Terminal voltages for 20%, 60%, and 100% penetrations with single-phase unbalanced and balanced scenarios are shown in Figure 6:18. For 20%, 60% and 100% penetration, the minimum voltage on the terminals are 0.89, 0.8 and 0.78 p.u. respectively in the unbalanced scenario. Terminal voltages are comparatively less in magnitude in the unbalanced scenario compared to the balanced scenario for the same penetration level.



(a) (b)

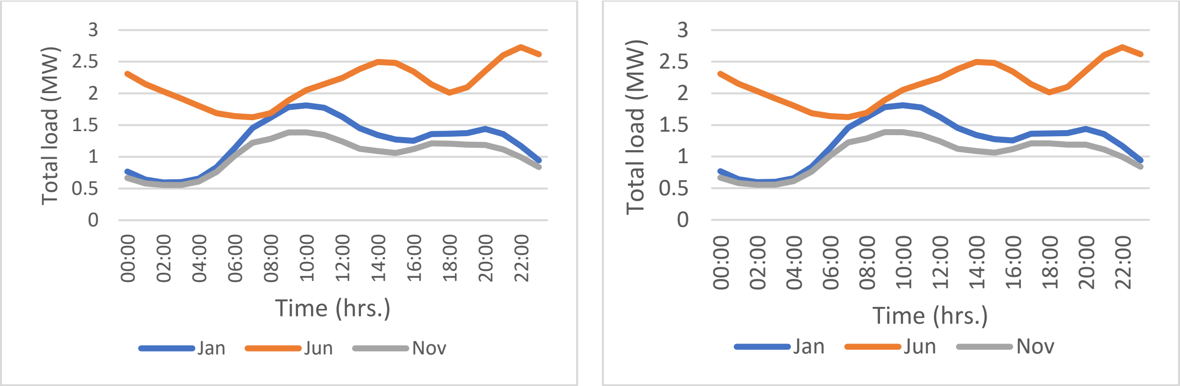
(c)

Figure 6:19. Transformer phase loading for (a) EV-20% (b) EV-60% (c) EV-100% penetration levels

Transformer phase loadings for 20%, 60%, and 100% penetrations with single phase unbalanced and balanced scenarios are shown in

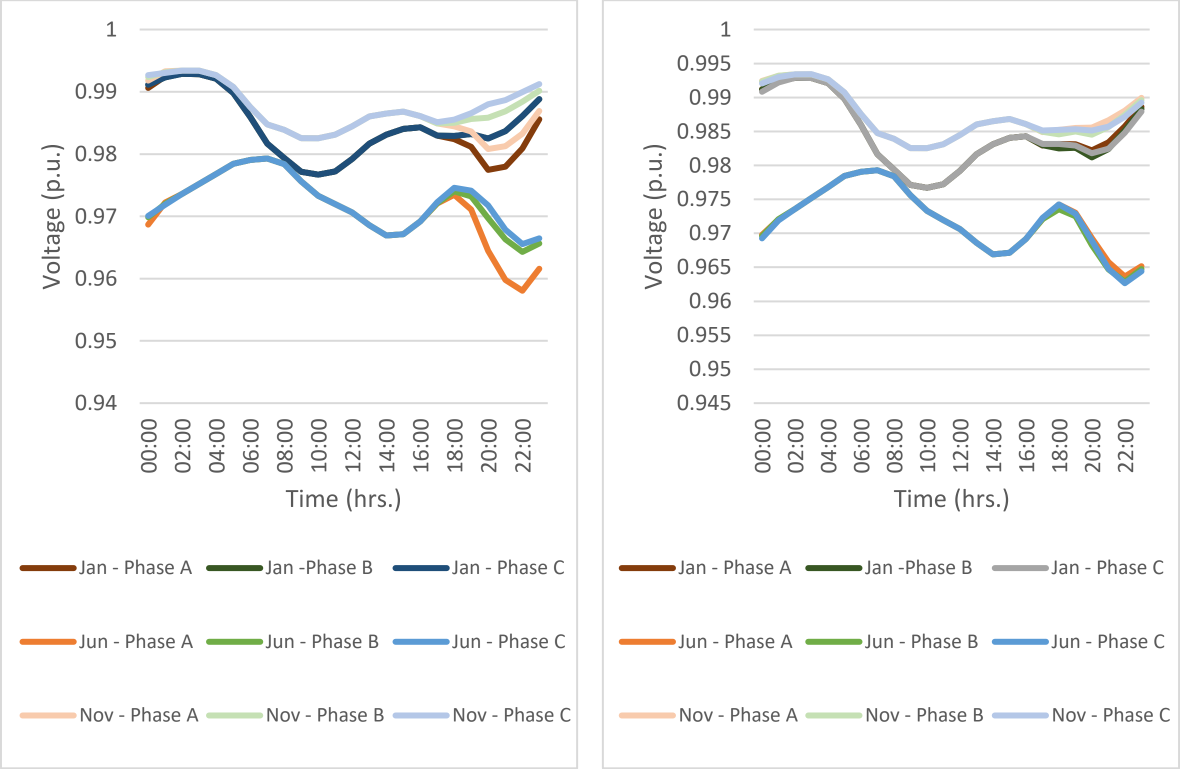
Figure 6:*19*.

In Figure 6:20, the system demand and the corresponding phase-wise voltages have been shown for three months of the year for both cases. As can be seen, even though the system load is identical, in the unbalanced system where a higher share of EVs was connected to Phase A, Phase A had the lowest voltage for all the months. Another observation that can be made is that during June, when the load is higher compared to January and November, the voltages were the lowest, leading to the degradation of Phase A's voltage. In comparison, in the balanced system, all the three phases had almost equal voltages, with the least voltages happening in June.



(a) System demand CS2(a)

(b) System demand CS2(b)



(c) Phase voltages CS2(a)

(d) Phase voltages CS2(b)

Figure 6:20: System demand and phase voltage at LV side of Transformer 8, for unbalanced system and balanced System

6.7 Coordinated Aggregate Charging

In this study, three case studies are performed to compare the impact of domestic and public charging stations. The three case studies are,

- Case study-1: Only Domestic Load is present
- Case study-2: Domestic Load and Domestic Chargers are present
- Case study-3: Domestic Load, Domestic Chargers and Public Chargers are present

In this case, public charging stations with a capacity of 1.02 MW are introduced into the system, along with 3-phase and 1-phase domestic charging. It is assumed that 50% of the households have 1-phase chargers and the other 50% have 3-phase chargers. The households with 3-phase chargers have a 7-kW charger with a four-wheeler of 30-kWh battery, and the ones with 1-phase chargers have a 3.3-kW charger with a 4-wheeler of 15-kWh battery. A total of ten public charging stations have been placed at different locations in the network. Five public charging stations, each with four chargers rated at 25 kW, and five public charging stations with a rated cumulative capacity of 104 kW (four 11 kW and 15 kW chargers each) have been considered. The phase unbalances in this case study are provided in Table 6.3.

Table 6.3. Percentage of EVs connected to each of the phases

Case	Phase A	Phase B	Phase C
Case study 3 (a) - Unbalanced	80%	16%	4%
Case study 3 (b) - Balanced	34%	33%	33%

The arrival behaviour of EVs coming to the public charging station is shown in Figure 6.21.

The plug-in time of EVs started from 6:00 AM to 9:00 PM. The peak arrival time is from 9 AM to 12 AM, and the afternoon peak arrival time is from 5 PM to 9 PM.

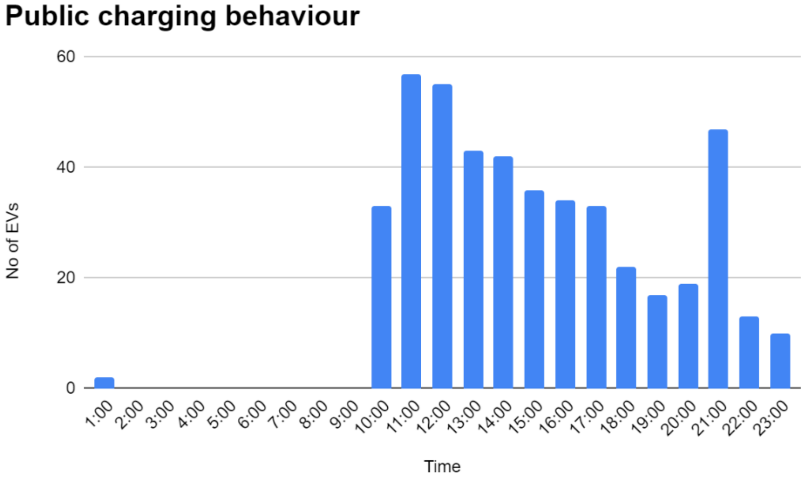


Figure 6:21. Arrival behaviour of EVs at public charging stations [75]

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[75] Sheldon Zhang, 'Campus Electric Vehicle Charging Stations Behaviour', Github

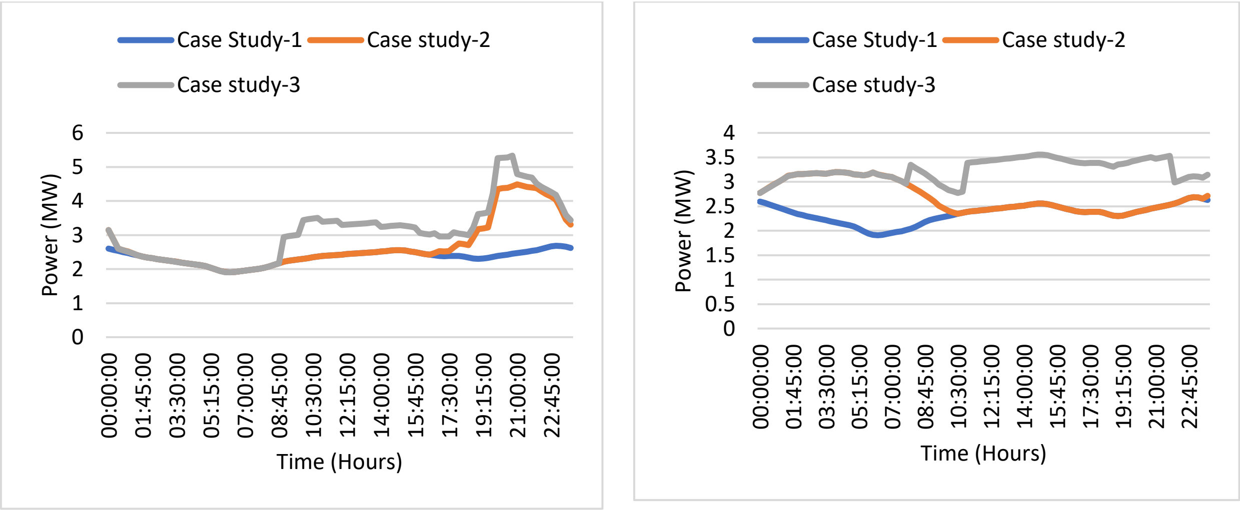
In the analysis of coordinated charging, the EVs are scheduled in such a way that the impact on peak loading is minimized, and the load curve is flattened. For achieving this, a higher share of EVs is charged during the off-peak hours and a lower share during the peak hours. This method of charging will reduce the overall stress on the grid. The penetration of EVs, in this case, is the same as discussed in the uncoordinated charging case. Domestic charging is scheduled from 12:00 AM to 9:00 AM, and public charging from 9:00 AM to 11:00 PM. The charger takes 4 hours to charge the battery fully. The considered phase unbalances are given in Table 6.4.

Table 6.4. Phase unbalance for the two cases

Case	Phase A	Phase B	Phase C
Scenario 3(a)	80%	16%	4%
Scenario 3(b)	34%	33%	33%

6.8 Results: Coordinated Charging

6.8.1 Scenario:3(a) - Unbalanced

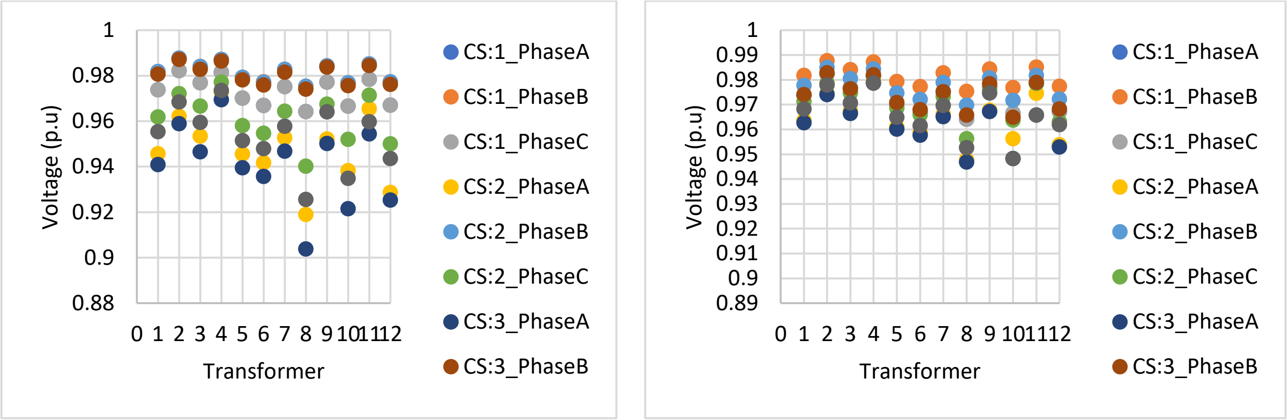


(a) (b)

Figure 6:22: Power demand due to (a) uncoordinated charging (b) coordinated charging

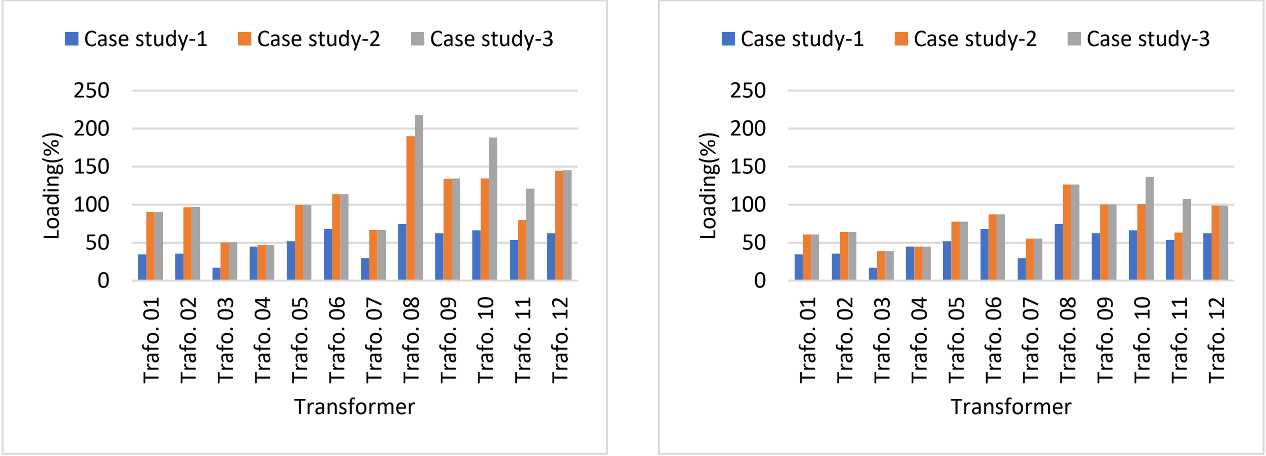
From Figure 6:22(a), it can be observed that the peak load in the uncoordinated charging scenario is increased from 2.59 MW to 4.51 MW for residential charging and 5.35 MW for public charging. The increase in peak load is less in the coordinated scenario - from 2.59 MW to 3.19 MW for residential charging and 3.55 MW for public charging - as shown in Figure 6:22(b). The peak demand due to uncoordinated public charging is reduced from 5.35 MW to 3.55 MW due to coordinated public charging. The peak demand is reduced by 50.7% by the utilization of coordinated charging over uncoordinated charging. The phase voltages under all the case studies for uncoordinated and coordinated charging are shown in

Figure 6:23. It is evident that the voltage for each phase varies significantly due to the varying number of connected EVs on each phase of the network. The lowest voltage is 0.9 p.u in the uncoordinated case, whereas 0.945 p.u. in the coordinated case. Phase A voltages in the three case studies are the lowest compared to the other phases.



(a) (b)

Figure 6:23. Transformer voltages due to (a) uncoordinated charging (b) coordinated charging

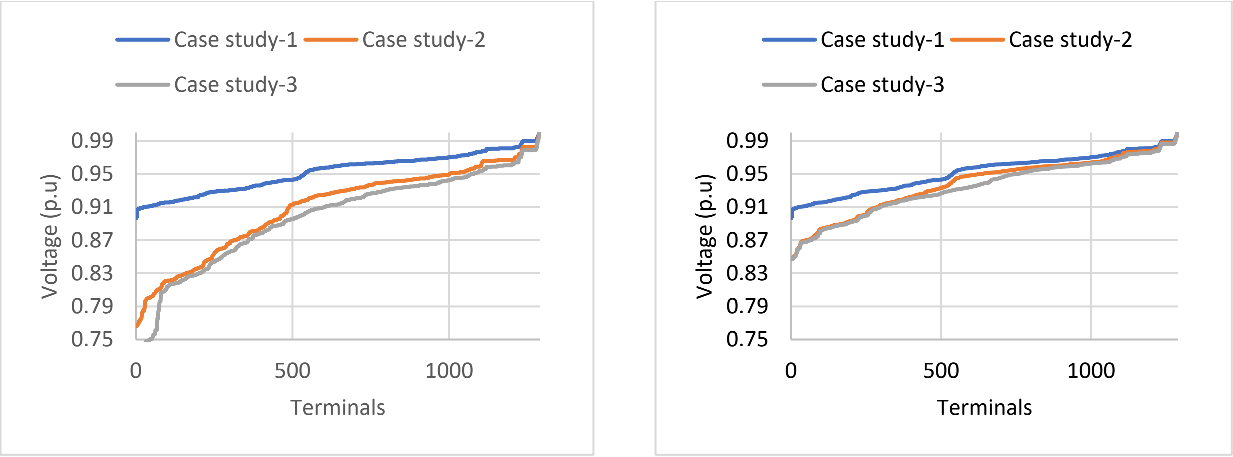


(a) (b)

Figure 6:24. Transformer loadings due to (a) uncoordinated charging (b) coordinated charging

Five of the LV distribution transformers, shown in Figure 6:24(a), are overloaded due to domestic EV charging. The overloading is witnessed in 1 other transformer additionally and there is further increase in overloading in three already overloaded transformers when public charging is added in the uncoordinated scenario. The overloading of transformers decreases in the coordinated charging scenario. In this scenario, only three of the LV distribution transformers, shown in Figure 6:24(b), are overloaded with domestic charging. The overloading increased in additional two transformers due to public charging.

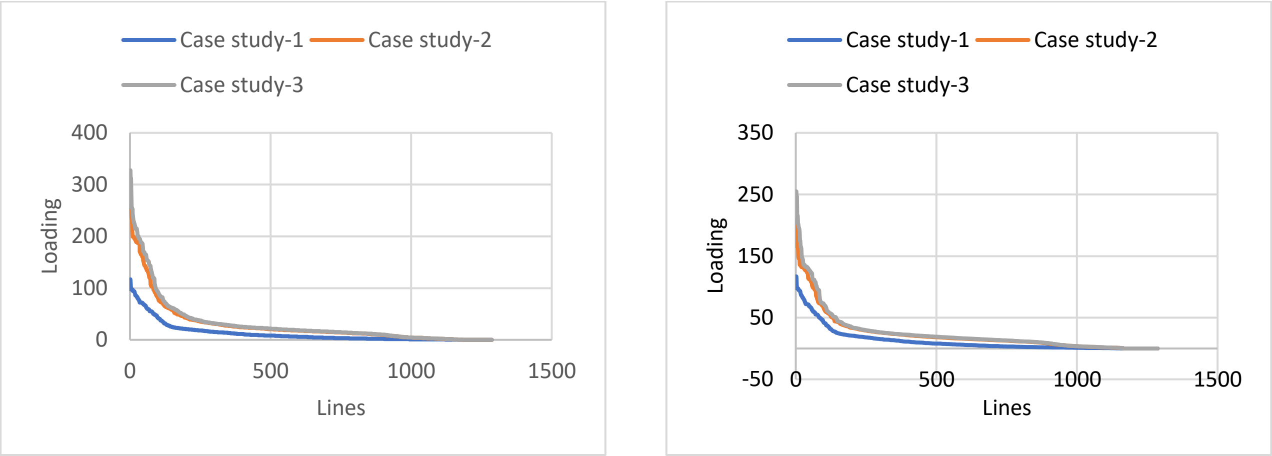
From Figure 6:25(a), it can be observed that around 600 nodes in the network have voltages lower than 0.9 p.u. for residential and public charging in the uncoordinated charging scenario (Case study-3). In contrast, only 258 nodes in the network are below the lower voltage limit of 0.9 p.u. in the coordinated charging scenario, as shown in Figure 6:25(b).



(a)

(b)

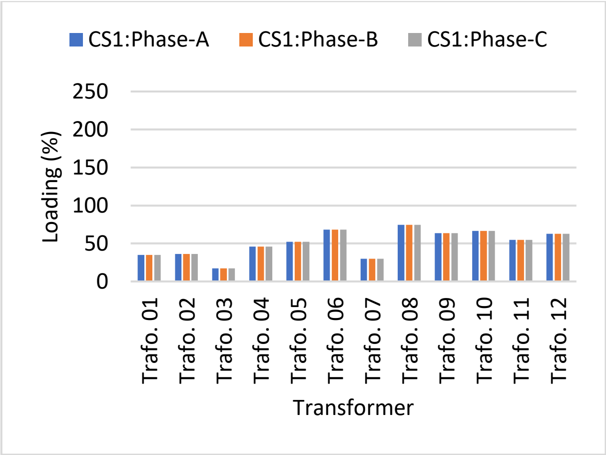
Figure 6:25. Terminal voltages due to (a) uncoordinated charging (b) coordinated charging

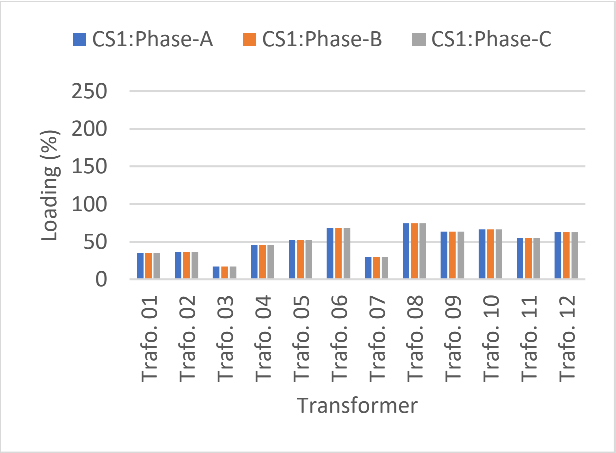


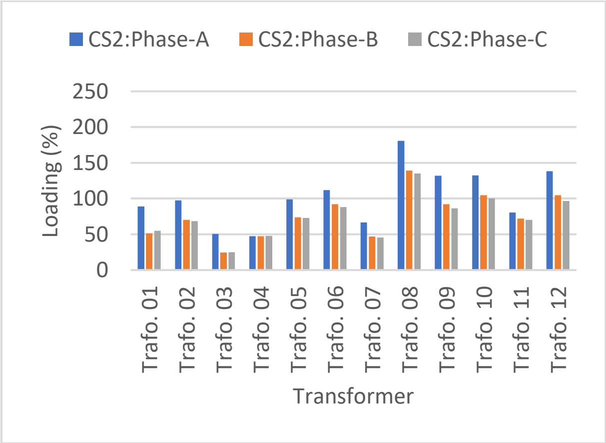
(a) (b)

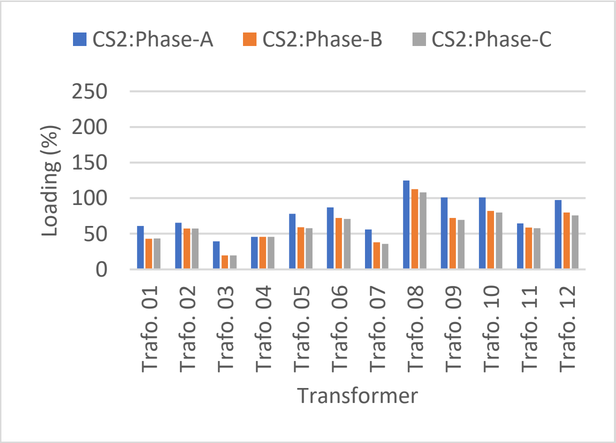
Figure 6:26. Line loadings due to (a) uncoordinated charging (b) coordinated charging

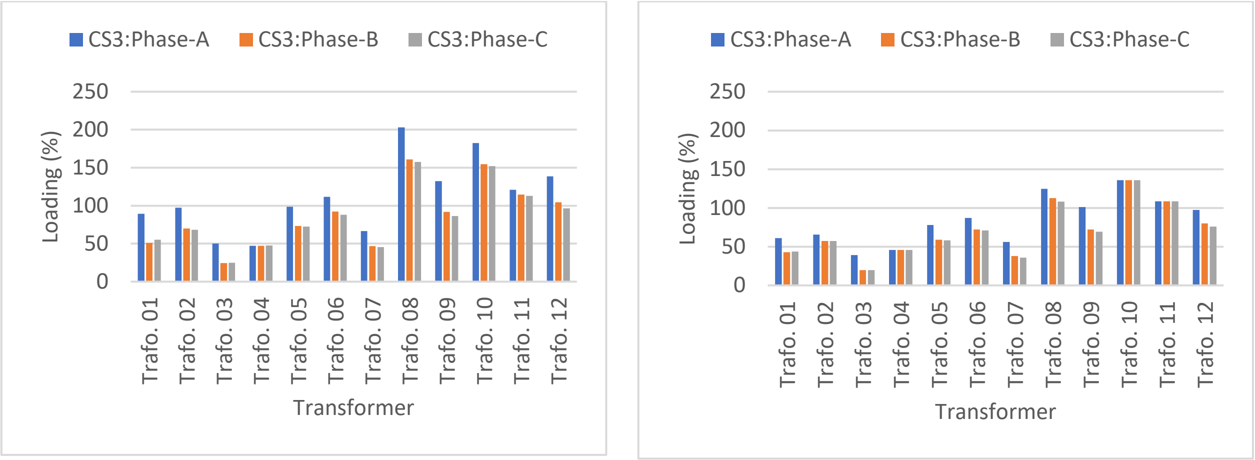
It can also be observed that around 100 lines in the network are overloaded for residential and public charging in the uncoordinated charging scenario (Case study - 3), as shown in Figure 6:26(a). Only 60 lines in the network are overloaded for residential and public charging in the coordinated scenario, as shown in Figure 6:26 (b).











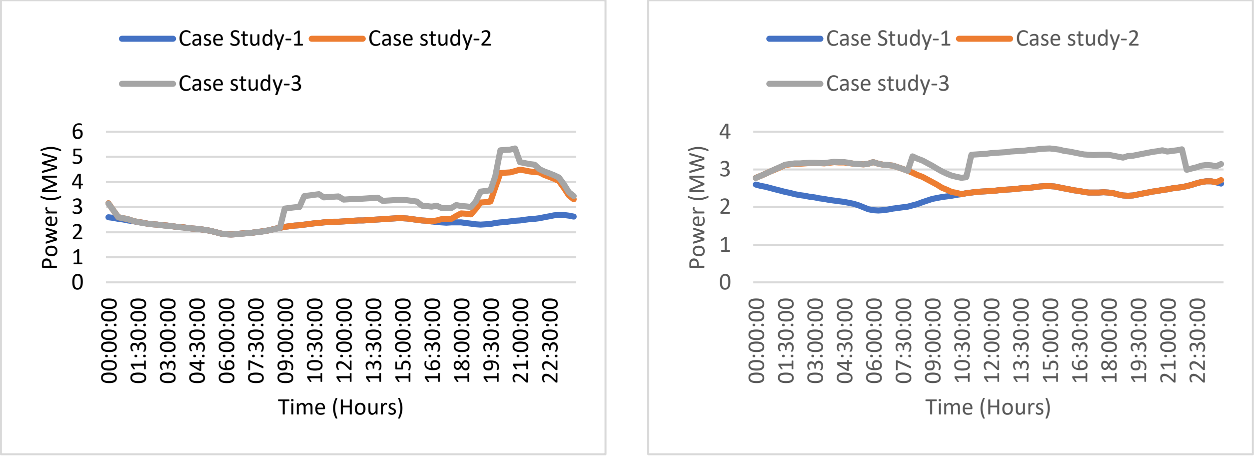
(a) Uncoordinated charging

(b) Coordinated charging

Figure 6:27: Transformer loadings shown for the different cases and with (a) uncoordinated charging and (b) coordinated charging

As the penetration is not equal in all the phases, phase-A in transformer-8 is highly overloaded for residential charging with around 180% loading and reaches even up to 200% during public charging, as seen in Figure 6:27(a) for uncoordinated charging. With coordinated charging the phase A of the transformer is loaded at 120% for residential charging, and 124% with addition of public charging, as seen in Figure 6:27(b).

6.8.2 Scenario:3(b) – Balanced EV charging

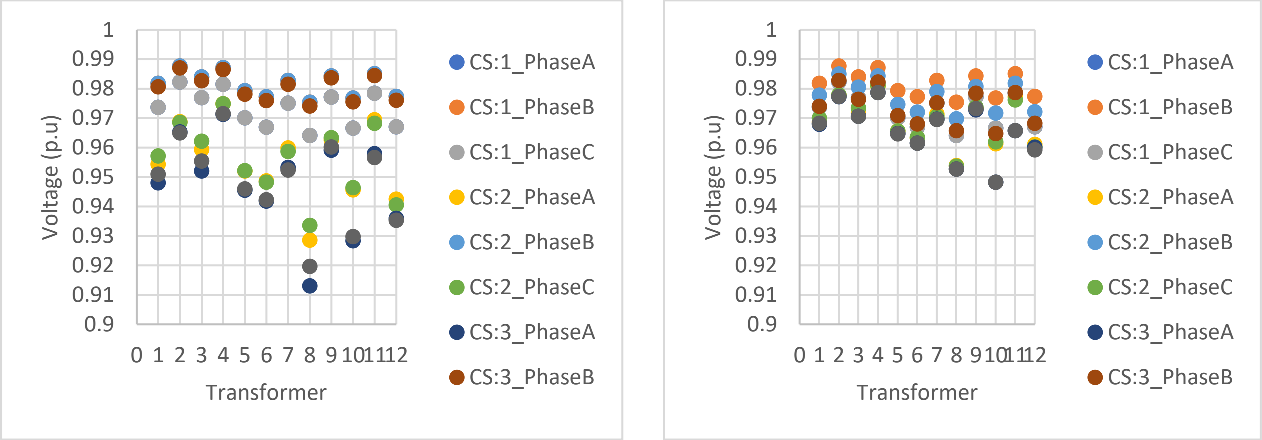


(a)

(b)

Figure 6:28. Power demand due to (a) uncoordinated charging (b) coordinated charging

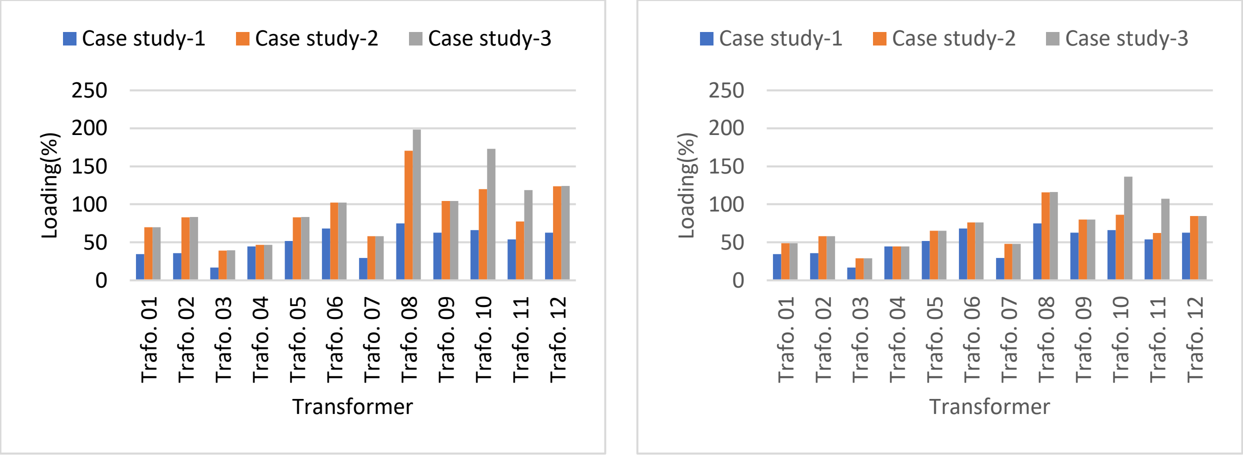
Figure 6:28(a) shows that the peak load in the uncoordinated charging scenario increased from 2.59 MW to 4.48 MW for residential charging and 5.33 MW for public charging. The increase in peak load is less in the coordinated scenario, from 2.59 MW to 3.19 MW for residential charging and 3.55 MW for public charging, as shown in Figure 6:28(b). The peak demand due to uncoordinated public charging is 5.33 is reduced to 3.55 due to coordinated public charging.



(a) (b)

Figure 6:29. Transformer voltages due to (a) uncoordinated charging (b) coordinated charging

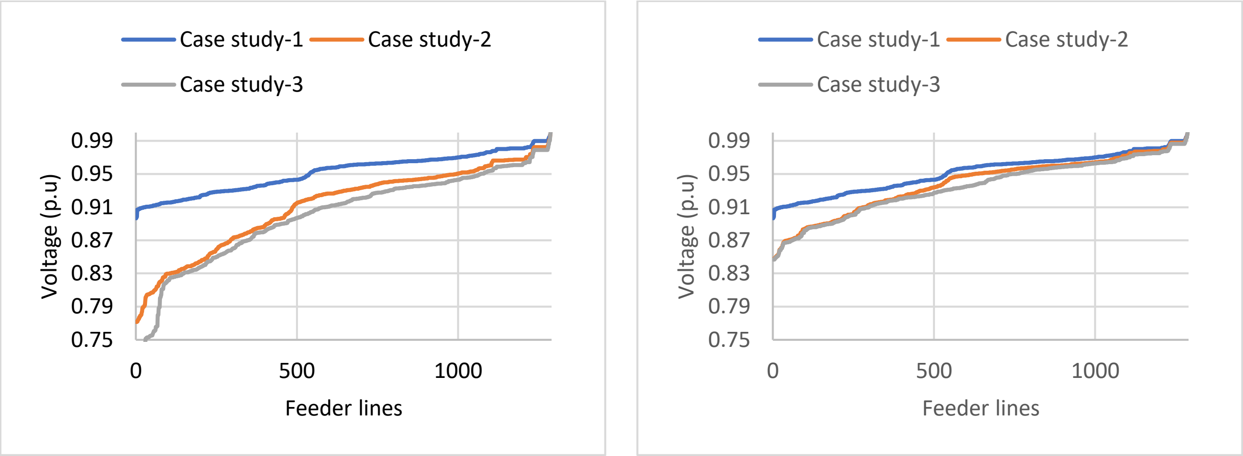
The phase voltages of all the case studies for uncoordinated and coordinated charging are shown in Figure 6:29. The voltage for each phase varies significantly due to the connection of EVs to the network. The lowest voltage is 0.91 p.u in the uncoordinated charging case, whereas 0.95 p.u. in the coordinated case.



(a) (b)

Figure 6:30. Transformer loadings due to (a) uncoordinated charging (b) coordinated charging

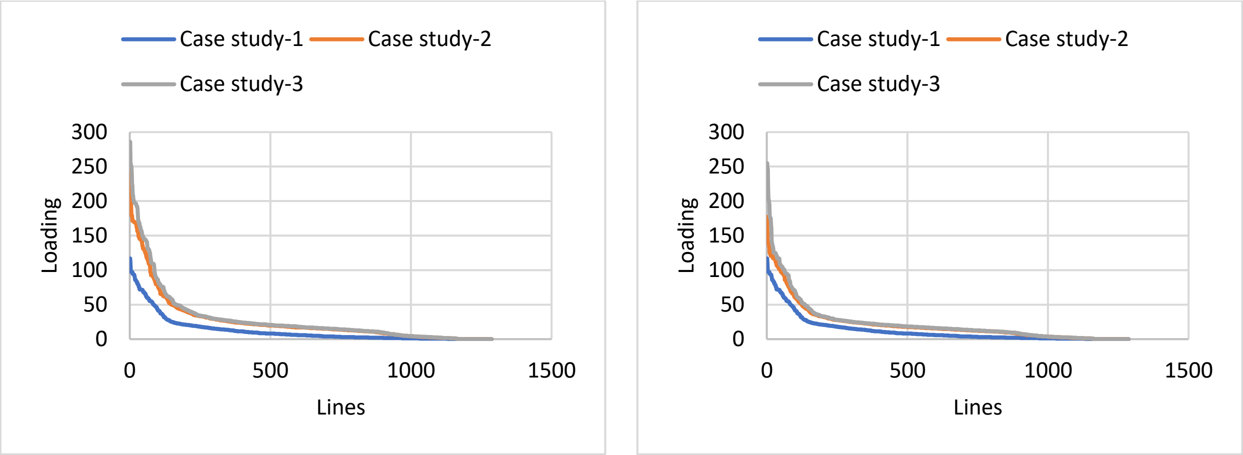
Five of the LV distribution transformers, shown in Figure 6:30 (a), are overloaded for domestic charging. With addition of public charging, there is 1 additional transformer being overloaded and further increase in loading of 5 transformers. Only five of the LV distribution transformers, shown in Figure 6:30(a) are overloaded for domestic uncoordinated charging, while using coordinated charging, the overloading decreased to just one transformers due to domestic charging. Even with addition of public charging, only 3 of the transformers are overloaded with coordinated charging, against the 6 transformers being overloaded in the uncoordinated scenario.



(a) (b)

Figure 6:31. Terminal voltages due to (a) uncoordinated charging (b) coordinated charging

It can be observed that around 585 terminals in the network breach the lower voltage limit of 0.9 p.u. for residential and public charging in the uncoordinated charging scenario (Case study -3), as shown in Figure 6:31(a). In contrast, only 293 terminals in the network are below the lower voltage limit in the coordinated charging scenario, as shown in Figure 6:31(b).



(a) (b)

Figure 6:32. Line loadings due to (a) uncoordinated charging (b) coordinated charging

Around 80 lines in the network are overloaded for residential and public charging in the uncoordinated charging scenario, as shown in Figure 6:32(a). Only 40 lines are overloaded for residential and public charging in the coordinated scenario, as shown in Figure 6:32(b).

(a) Uncoordinated (b) Coordinated

Figure 6:33: Transformer phase loadings due to (a) uncoordinated charging (b) coordinated charging

As the penetration is equal in all the phases, transformer-8 is highly overloaded for residential charging and increased to 180% for public charging, as seen in Figure 6:33(a) for uncoordinated charging. This loading is only 110% for residential charging, evident from Figure 6:33(b), for coordinated charging.

6.9 Conclusion

Based on the analysis done, it can be concluded that EV integration may introduce significant challenges to the distribution network operator, specifically feeder congestion and voltage issues. The impacts would be further exacerbated, with unbalanced phase loadings due to integration of single phase EV chargers. This entails that the distribution system operator would need to actively monitor the network health characteristics, the existing number of EV chargers in the distribution feeder, the power capacities of the EV chargers as well the phases the chargers are connected to, prior to providing connection permissions for EV charger installation.

With rural grids which have longer lines and highly loaded transformers, the impact of EV integration is expected to be higher, with poorer voltage profiles and higher transformer loading.

With the requisite regulations and infrastructure, the EV chargers could be configured with smart charging capabilities that can help alleviate the above mentioned impacts of EV integration. In the subsequent sections, the capabilities of EV in helping the grid operator to better manage the grid have been explored.

Chapter 7. Reactive Power Support from Electric Vehicles

7.1 Introduction

One of the critical requirements for maintaining system health is the availability of adequate reactive power reserve. Usually preferred to be generated locally in the distribution network, the network operators often make significant investments in procurements and installation of reactive power compensation devices, such as capacitor banks, synchronous condensers etc. However, DC EV chargers can be configured to enable four quadrant operation and help in reactive power compensation for the network [76]. The four-quadrant operation of DC chargers enables them to provide reactive support irrespective of whether the charger is being used for charging an EV. However, the quantum of reactive support is capped by the rated capacity of the charger and the EV charging active power load. In this chapter, the capabilities of an EV charging station to support the system voltage profile under different operating conditions are explored.

7.2 Test System Modelling

In this section, the details of the test system considered for the analysis, the considered EV charging stations, and the behavior modelling of the EV users have been detailed.

7.2.1 Distribution Grid

The distribution system modelled to study reactive support services from EV is shown in

Figure *7:1*, which is an actual urban LV distribution grid in India. The grid 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 connected load of 2.57 MW. The downstream network of the transformers has been defined as separate feeders, as given in Table 7.1.

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[76] 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.

Table 7.1: 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

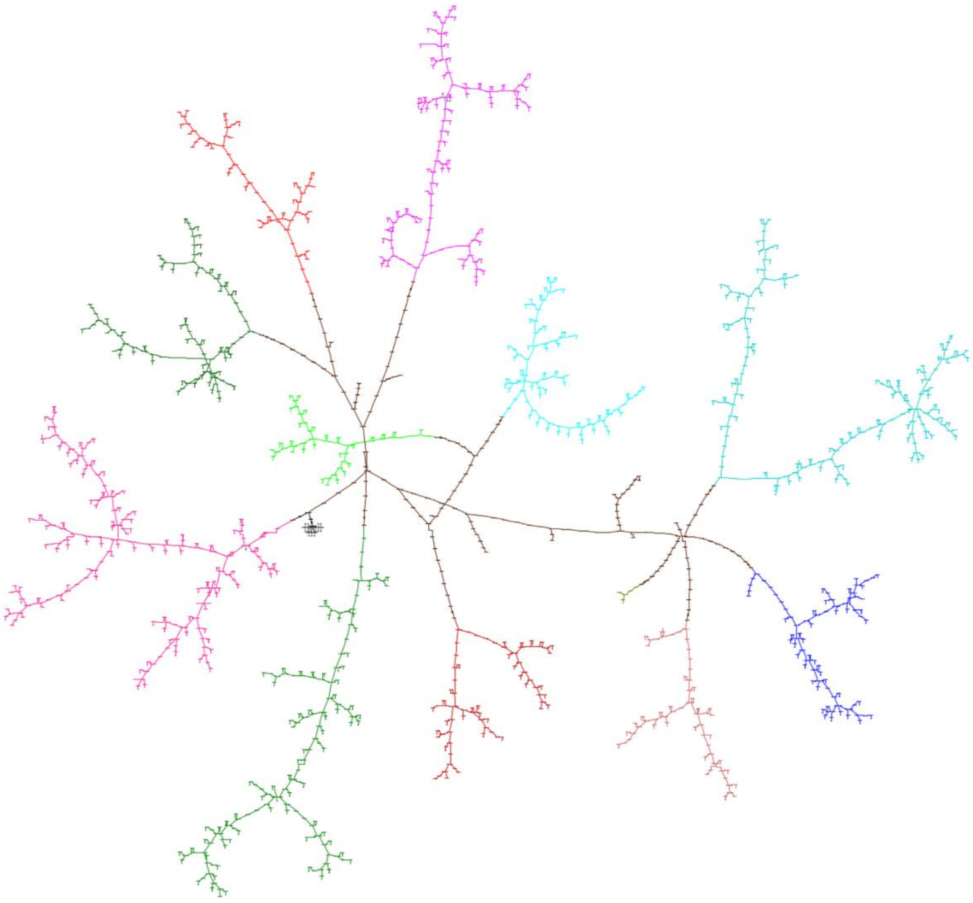

Figure 7:1: Indian LV distribution grid considered for study

7.2.2 Public Charging Station Modelling

The public charging station (PCS) has been modelled as a combination of different charger types and ratings. The PCS consists of 15 chargers with 5 AC chargers of 22 kW, seven 50-kW DC chargers, two 150-kW DC chargers and one 200-kW DC charger. The maximum power capacity of the PCS is 0.96 MW. The chargers are connected to an 11 kV bus through a 1.25-MVA 11/0.4 kV transformer. The layout of the charging station is presented in Figure 7:2.

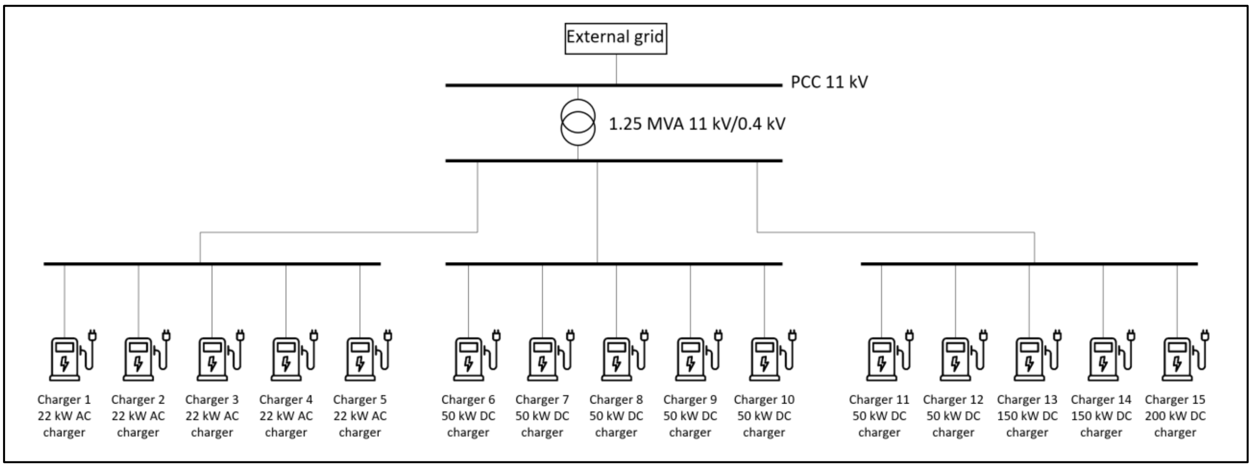

Figure 7:2: Layout of PCS

7.2.3 Charging Behaviour

A stochastic charging behavior model is also developed to model the EVs arriving at the PCS to charge their vehicle. In this model, a probabilistic arrival pattern of EVs arriving at the PCS is considered initially. This probability distribution, shown in Figure 7.3 is based on actual survey data collected from PCS in the state of Nebraska, USA, from 2013 to 2019[77]

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[77] Ahmad Almaghrebi et al., "Data-Driven Charging Demand Prediction at Public Charging Stations Using Supervised Machine Learning Regression Methods," *Energies* 13, no. 16 (January 2020): 4231, https://doi.org/10.3390/en13164231.

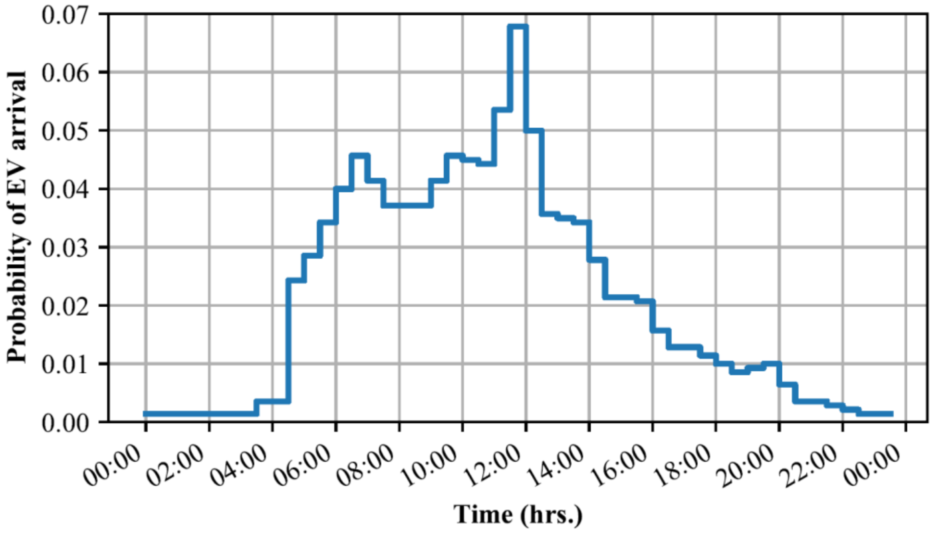

Figure 7:3: Probability of EV arriving at PCS[77]

Each EV arriving at the charging station has a randomized initial State of Charge (SoC), battery capacity, charger type and charger capacity. The EVs are then connected to chargers on a first-come first-served basis, with priority given to DC charging (if the vehicle is compatible to DC charging). The time required for charging is a function of the actual charging power $P_{charging}$, the rated capacity of the battery ($EV^{capacity}$) and the initial SOC of the EV (SOC_{init}) and the final required SOC (SOC_{final}), as given in Eq. 3.

$$T_{charging} = f\left(P_{charging}, EV^{capacity}, SOC_{init}, SOC_{final}\right) \qquad \text{Eq. 3}$$

However, the charging power of EVs is not constant. Different EV manufacturers have different charging curves designed for optimal EV performance in terms of battery and thermal management. The charging power of the EV can be determined using Eq. 4, where $P_{charging}^{rated}$ is the rated charging power of the EV and $\phi^{CC-CV}(SOC)$ is the charging curve of the EV, which is dependent on the SOC. The charging curve derived from a real-life data is used in this study, as illustrated in Figure 7:4.

$$P_{charging} = g\left(P_{charging}^{rated}, \phi^{CC-CV}(SOC)\right) \qquad \text{Eq. 4}$$

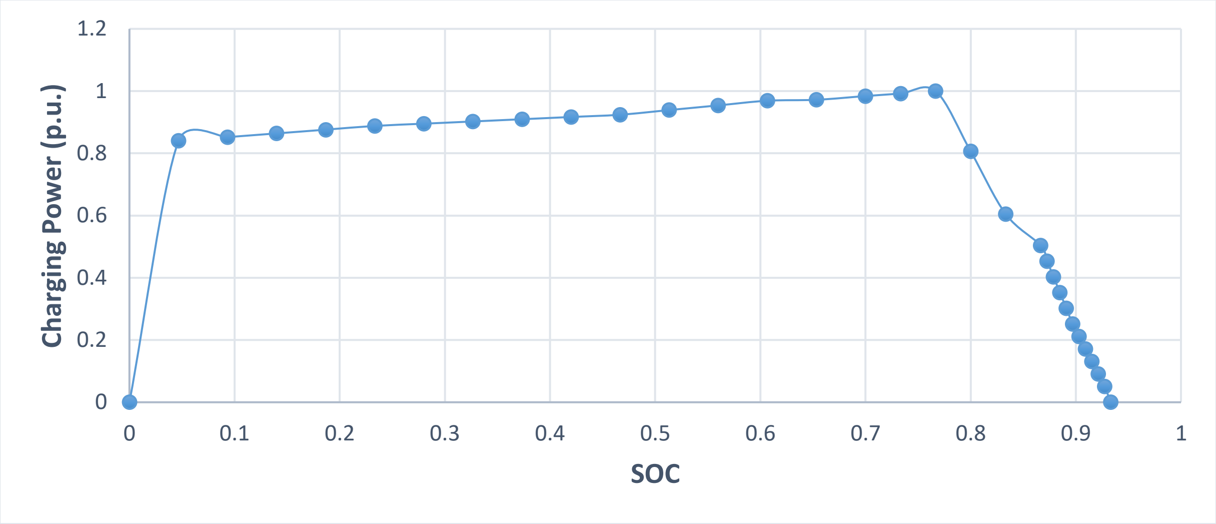

Figure 7:4: Charging profile of EV [78]

Once the EV arrives at the charging station, the assigned charger depends on its availability, capability and requirement. If the EV is capable of DC charging @ C_{fast} kW, where C_{fast} is the rated power of the highest capacity charger in the PCS, then the EV is allotted that charger (if it is available). If the charger is unavailable, the EV is connected to the next highest rated charger and so on. If no DC charger is currently available, the EV is plugged into an AC charger. The time of charging is also dependent on the charger the EV is connected to. If none of the chargers are available, the EV is not served as the PCS is unable to serve the EV. Queuing of EVs has not been considered in this study, as it is unlikely that an EV user would prefer to wait before plugging in their vehicle.

The initial and the final SOC of the EVs have been modelled as uniform distributions ranging from 0.2 to 0.5 for SOC_{init} and between 0.7 and 0.9 for SOC_{final}, as shown in Figure 7:5 and Figure 7:6, respectively.

The battery capacity of the vehicles arriving at the PCS has been modelled to take random values, following a normal distribution with a mean of 60 kWh and a standard deviation of 25 kWh. The resulting distribution is shown in Figure 7:7

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[78] Romain Mathieu et al., “Comparison of the Impact of Fast Charging on the Cycle Life of Three Lithium-Ion Cells under Several Parameters of Charge Protocol and Temperatures,” *Applied Energy* 283 (February 1, 2021): 116344, https://doi.org/10.1016/j.apenergy.2020.116344.

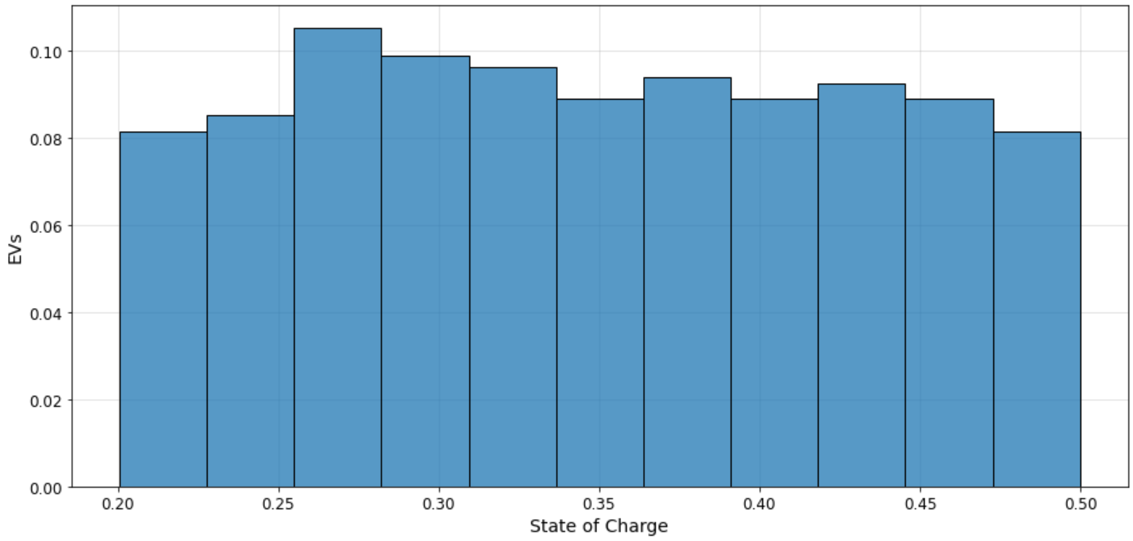

Figure 7:5: Range of SOC of EVs arriving at the PCS

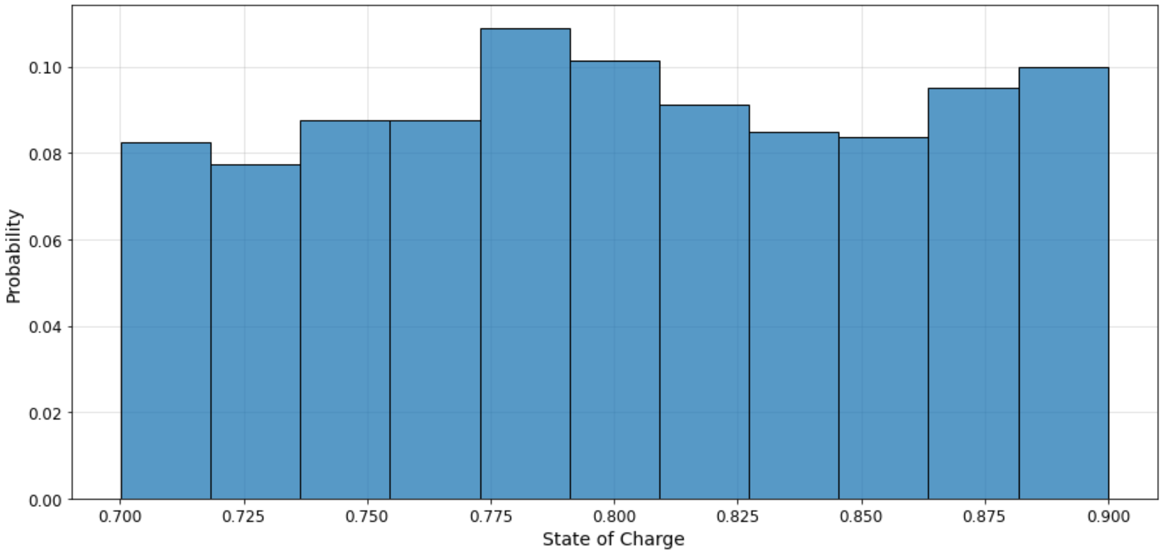

Figure 7:6: Range of SOC of EVs exiting the PCS

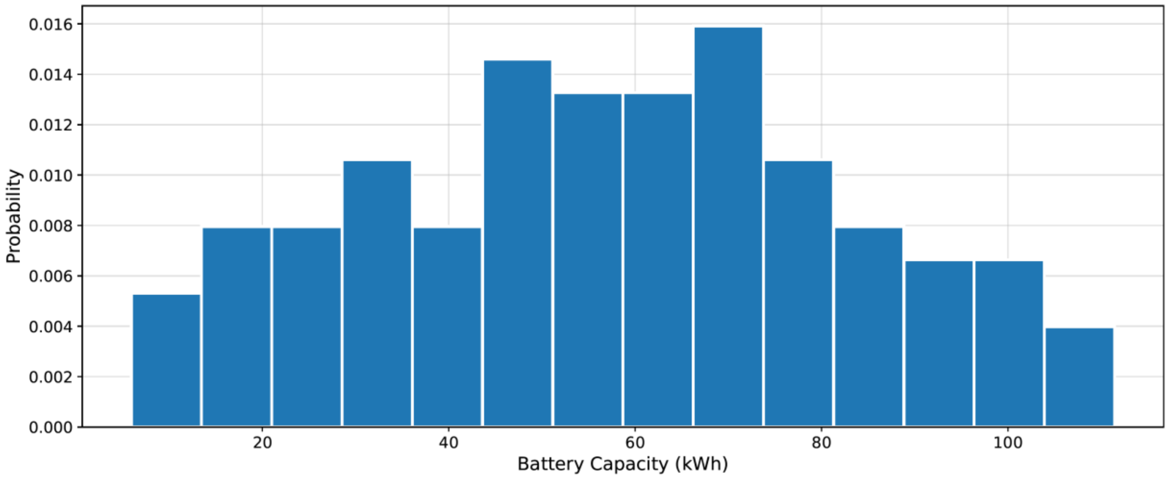

Figure 7:7: Battery capacity of vehicles arriving at the PCS

7.3 Reactive Support from EV

7.3.1 Control Topologies

Reactive support can be provided from any resource through three main control topologies, as given below.

7.3.1.1 Q Control

The Q control function maintains a constant reactive power independently of the grid voltage and the active power in the Point of Connection. This control function is shown as a horizontal line in Figure 7:8

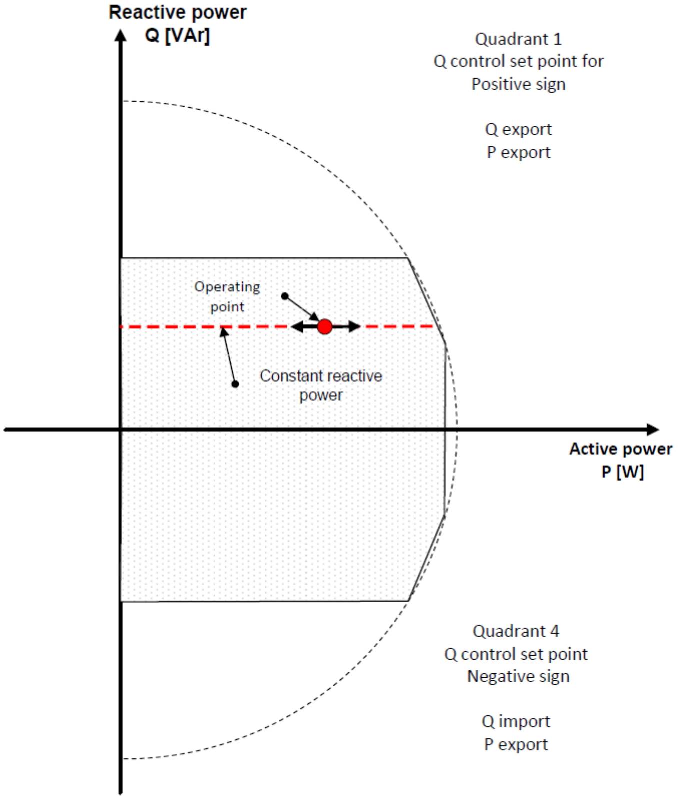

Figure 7:8: Q control

7.3.1.2 Power factor Control

The power factor control functionality controls the reactive power proportionally (determined by the droop) to the active power at the point of connection, which is illustrated by a line with a constant gradient in Figure 7:9.

7.3.1.3 Q(V) control

Q(V) is a control function that automatically controls the voltage within the voltage reference point. Depending on the deviation of the Point of Common Coupling (PCC) voltage from the set point, the reactive power absorbed/delivered is determined from the droop, as shown in Figure 7.10

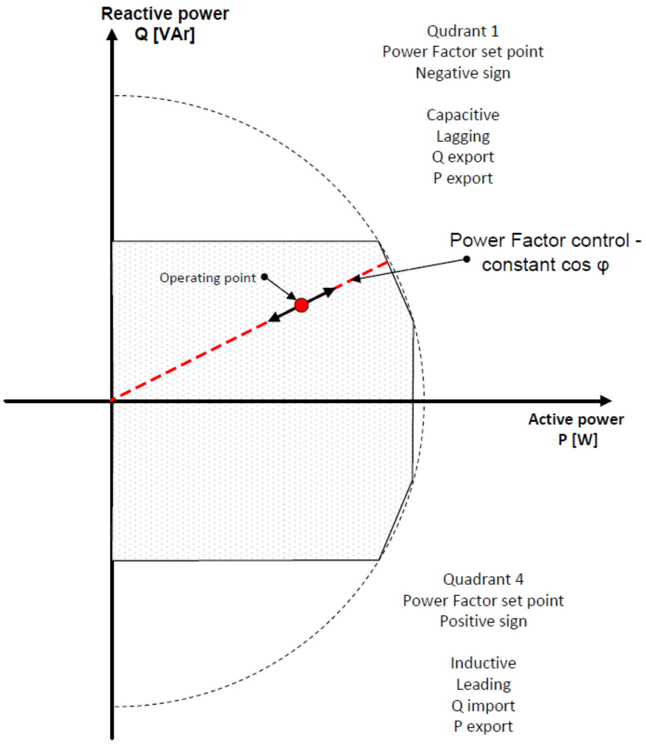

Figure 7:9: Power Factor Control

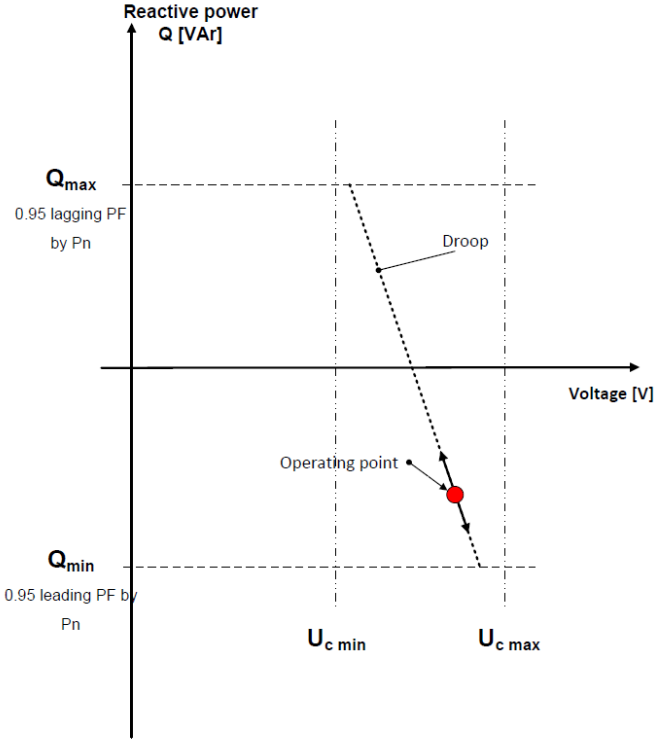

Figure 7:10: Automatic Voltage control

7.4 Case Studies

In this study, the public EV charging stations have been utilized as a reactive power resource to support the grid during periods of requirement. The reactive support from the charging station can potentially help improve the voltage profile of the system. However, as currently constituted, there is no reactive power market mechanism in place in Indian electricity market. Hence, the other revenue opportunities that can be explored under the existing regulations and market mechanism are,

- Large customers, such as industries or large commercial properties, are typically charged based on the apparent power drawn by the customer from the distribution grid, i.e., they are charged for both their active and reactive power consumption. These consumers can save on their electricity bills by utilizing the reactive power resources from their captive charging plants.
- The Indian Grid Code stipulates that a distribution entity should generate its own reactive power, and the consumption of reactive power from the transmission network is penalized[79]. So, these distribution utilities can also utilize reactive power from the EV charging stations to fulfil their reactive power demand.
- Reactive power supply from EV charging stations can improve the voltage profile of the network, thereby potentially helping to reduce the losses in the distribution utility.

7.4.1 Voltage Support

For analyzing the impact of reactive support from EV chargers on the distribution system, the representative Indian distribution system, as described in Section 3.2, has been used. The system condition at the base case when there is no support from EV chargers is shown in Figure 7*:11*. From the figure, the voltage profile is subpar for three different feeders, namely Feeder 2, Feeder 8, and Feeder 11, where the voltages are lower than 0.85 p.u. The voltage profile along Feeder 2, which is one of the least optimum in terms of voltage profile, has been shown in Figure 7:13. It shows that although the voltage at the LV side of the infeed transformer is at around 0.95 p.u., there is a sharp decline in the voltage profile along the distribution feeder.

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[79] The following conditions are applied. (Source: Indian Grid Code Regulation)

Penalized/Awarded	**Voltage conditions**	**Reactive power condition**
Penalized	V < 0.97 pu	Drawal
Penalized	V > 1.03 pu	Injection
Awarded	V < 0.97 pu	Injection
Awarded	V > 1.03 pu	Drawal

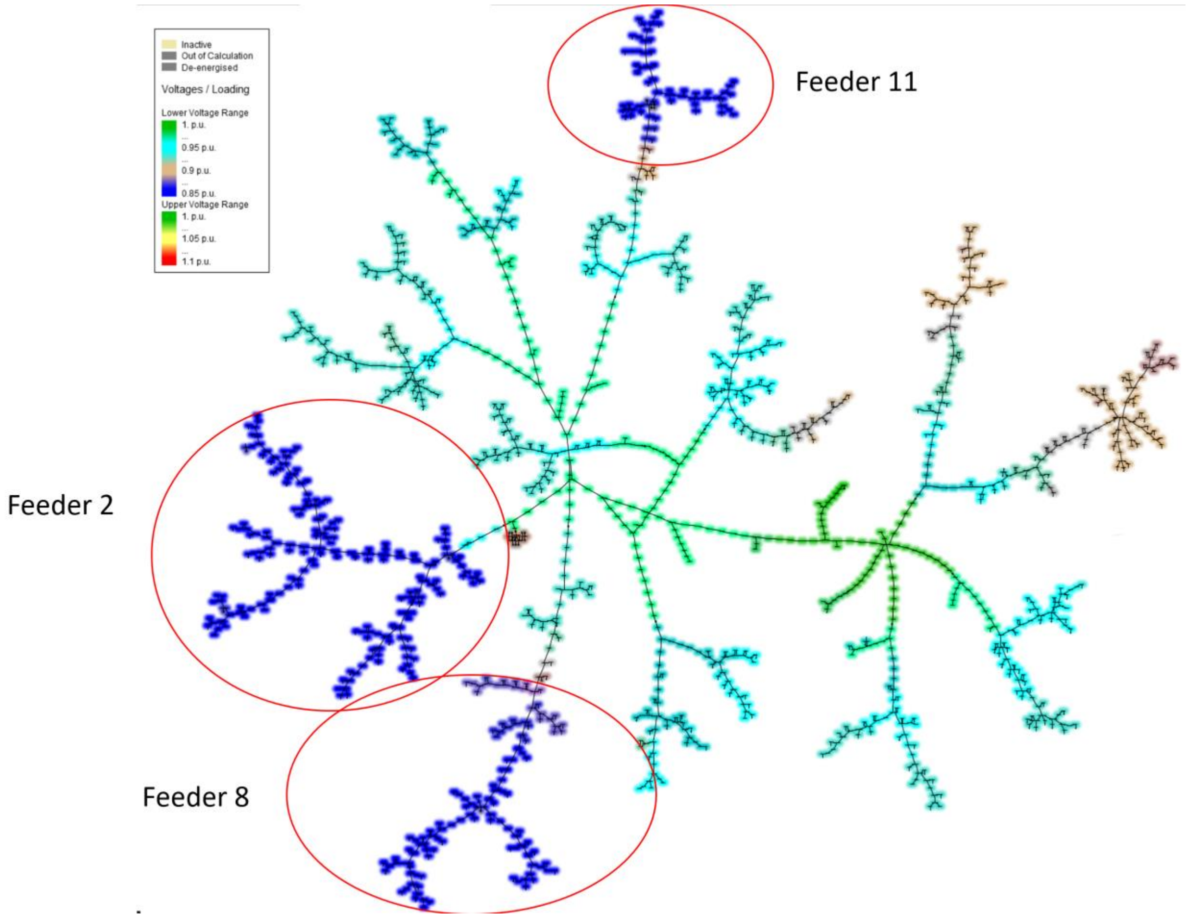

Figure 7:11: System voltages when no reactive support is provided from EV chargers

For reactive support, 8 DC Fast Chargers (DCFC) were installed at 6 different PCS locations, as shown in Figure 7:12. The DCFCs were strategically located at the three feeders with the poorest voltage profiles. The characteristics of the PCS are given in Table 7.2.

Table 7.2: 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

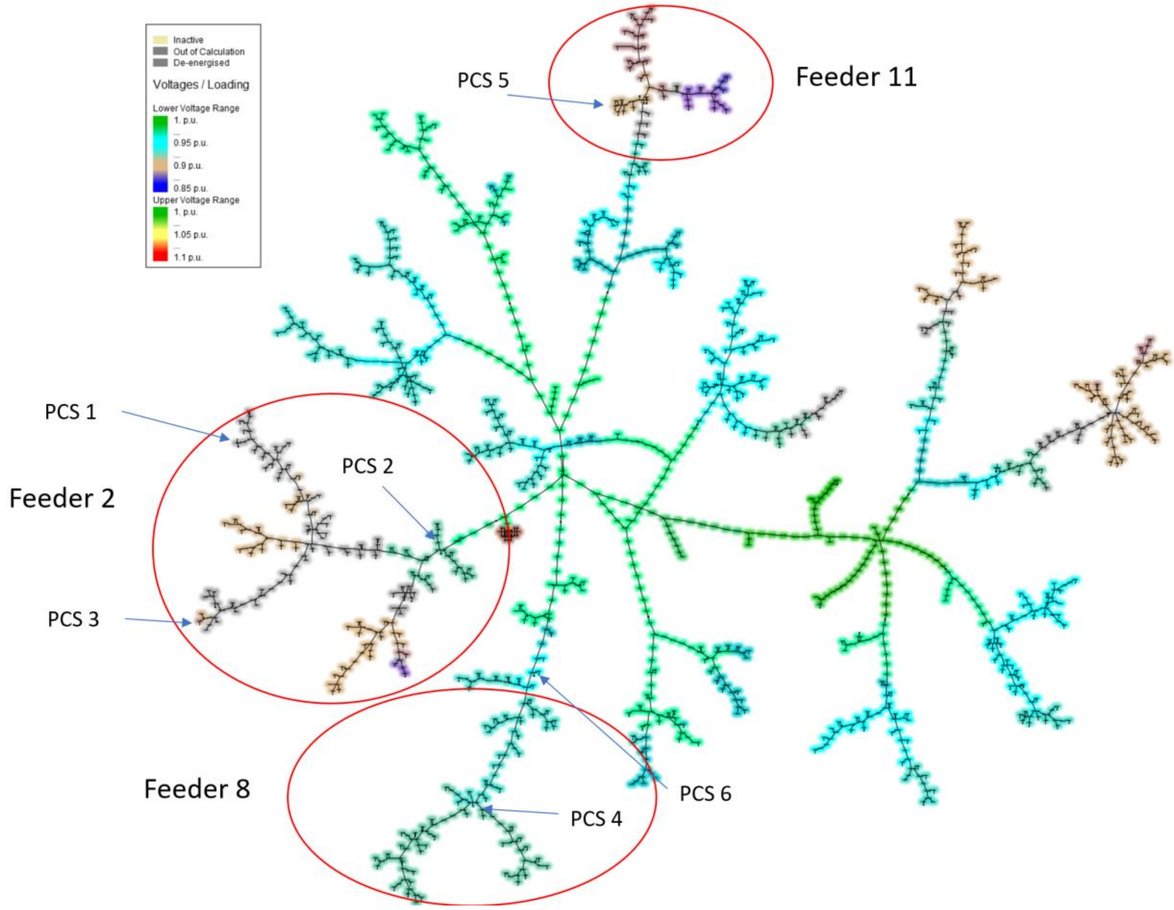

Figure 7:12: Improvement of voltage profile of the network by utilizing the reactive support from EV chargers

The voltage profile of the system with the addition of the PCSs has been shown in Figure 7:12. The voltage profiles of the affected feeders, i.e., Feeder 2, Feeder 8, and Feeder 11, all have seen a marked improvement in their voltages. The voltage profile along the length of Feeders 2, 8, and 11 with and without reactive power support from PCS have been shown in Figure 7:13, Figure 7:14, Figure 7:15, Figure 7:16, Figure 7:17, and Figure 7:18, respectively. Without any support, the voltage at the tail end of Feeder 2, Feeder 8, and Feeder 11 was around 0.8 p.u., 0.82 p.u. and 0.81 p.u., respectively. With the provision of reactive power support, the voltage at the tail end of these feeders improved to 0.91 p.u., 0.92 p.u. and 0.87 p.u. However, these voltage profiles have been shown for one instant (during the peak loading conditions).

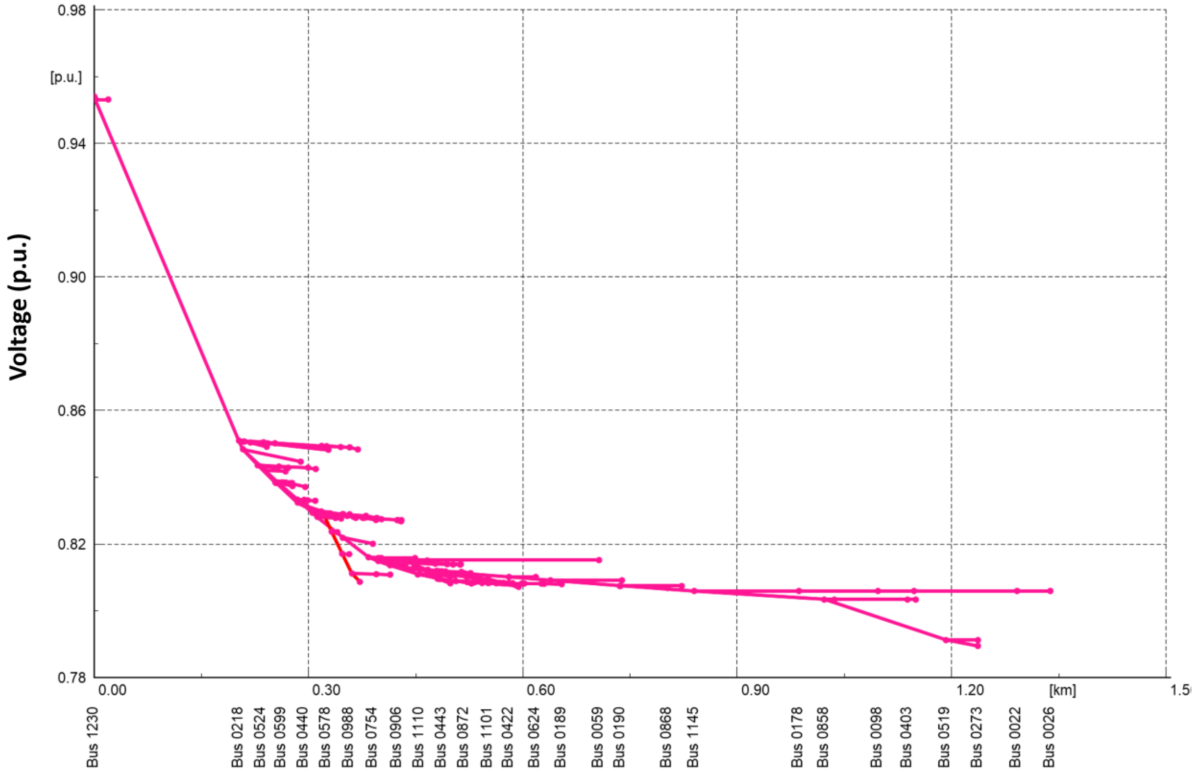

Figure 7:13: Voltage profile of Feeder 2 without any reactive support from EV chargers

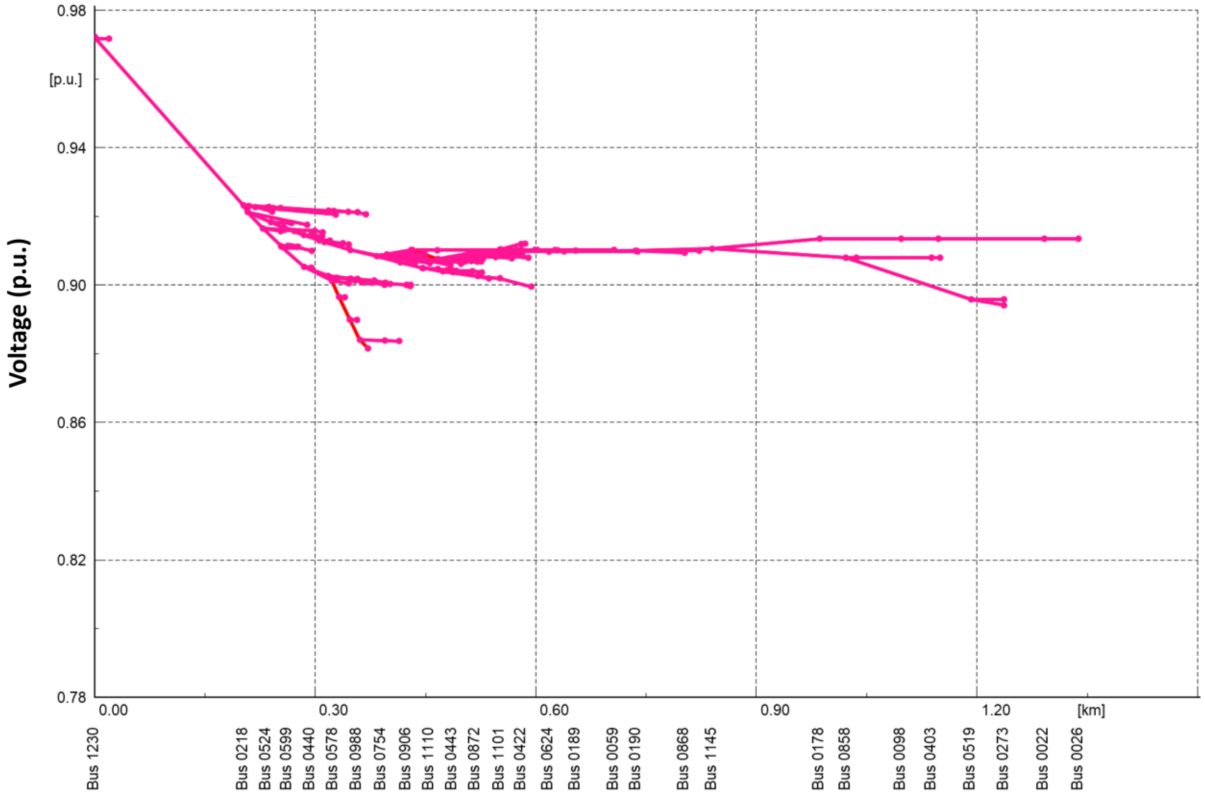

Figure 7:14: Voltage profile of Feeder 2 with reactive support from EV chargers

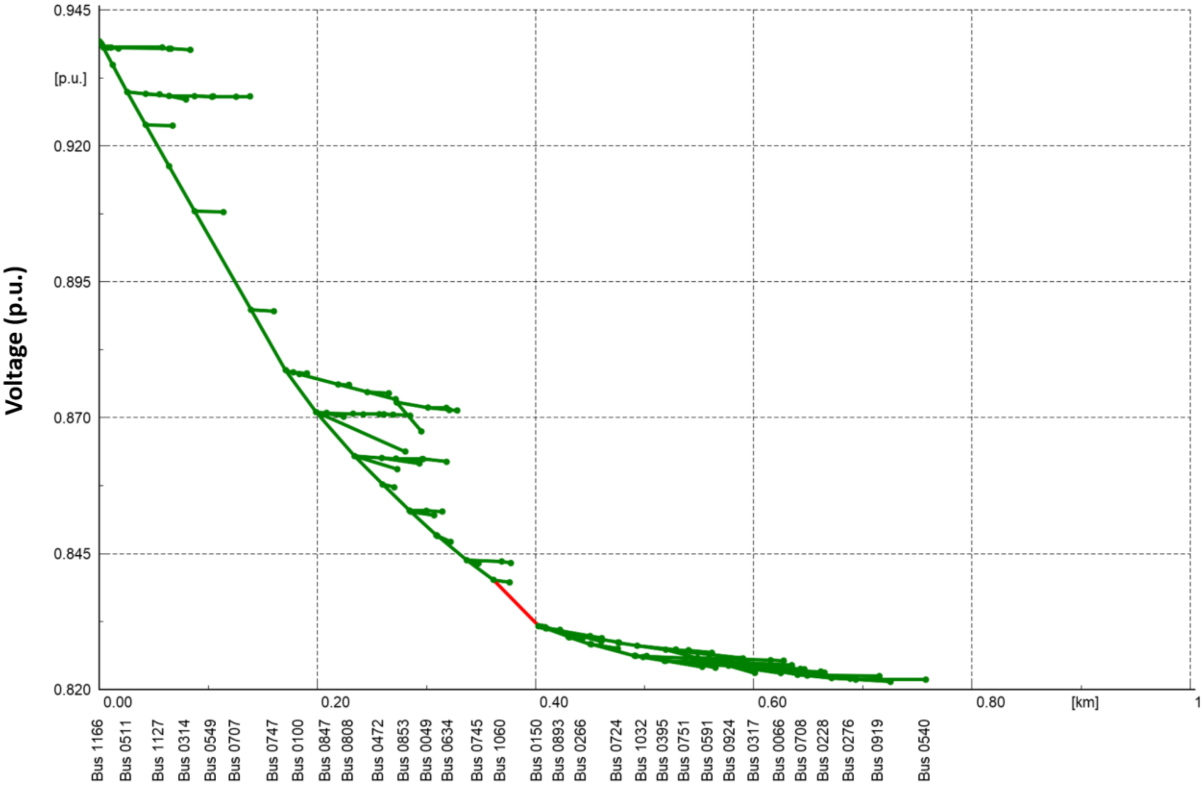

Figure 7:15: Voltage profile of Feeder 8 without any reactive support from EV chargers

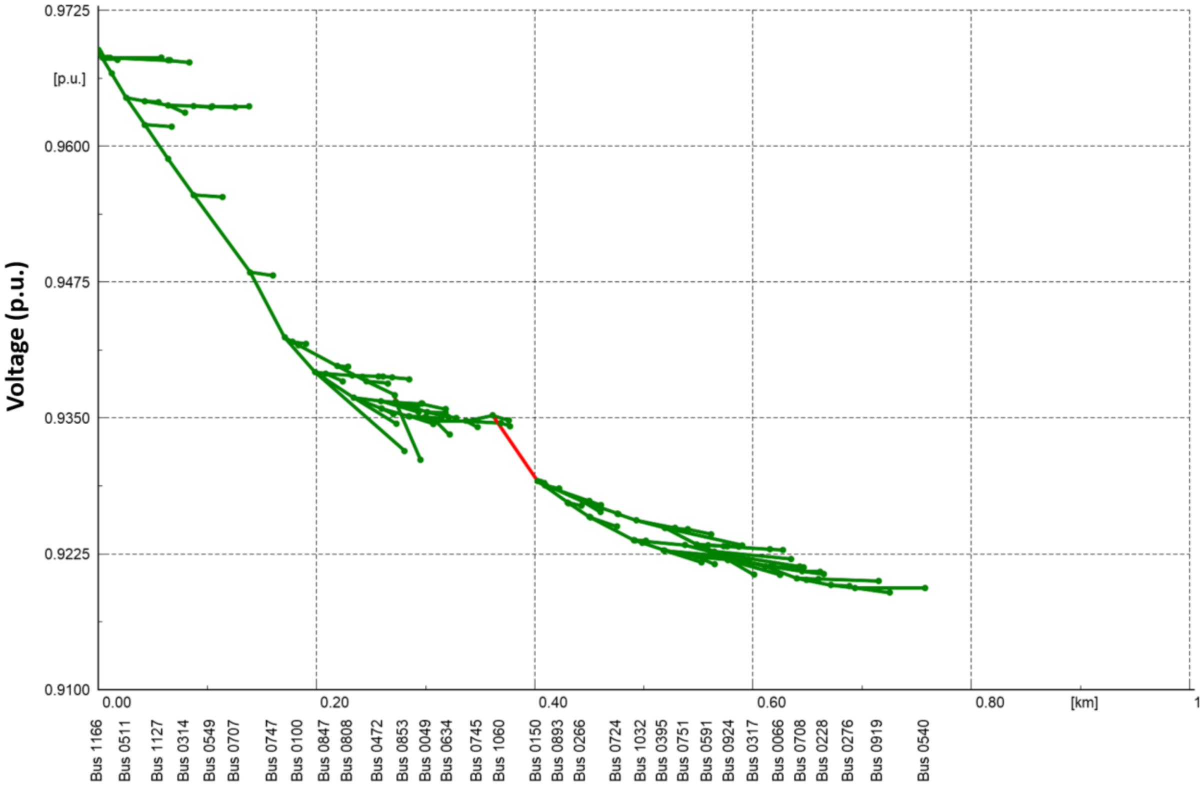

Figure 7:16: Voltage profile of Feeder 8 with reactive support from EV chargers

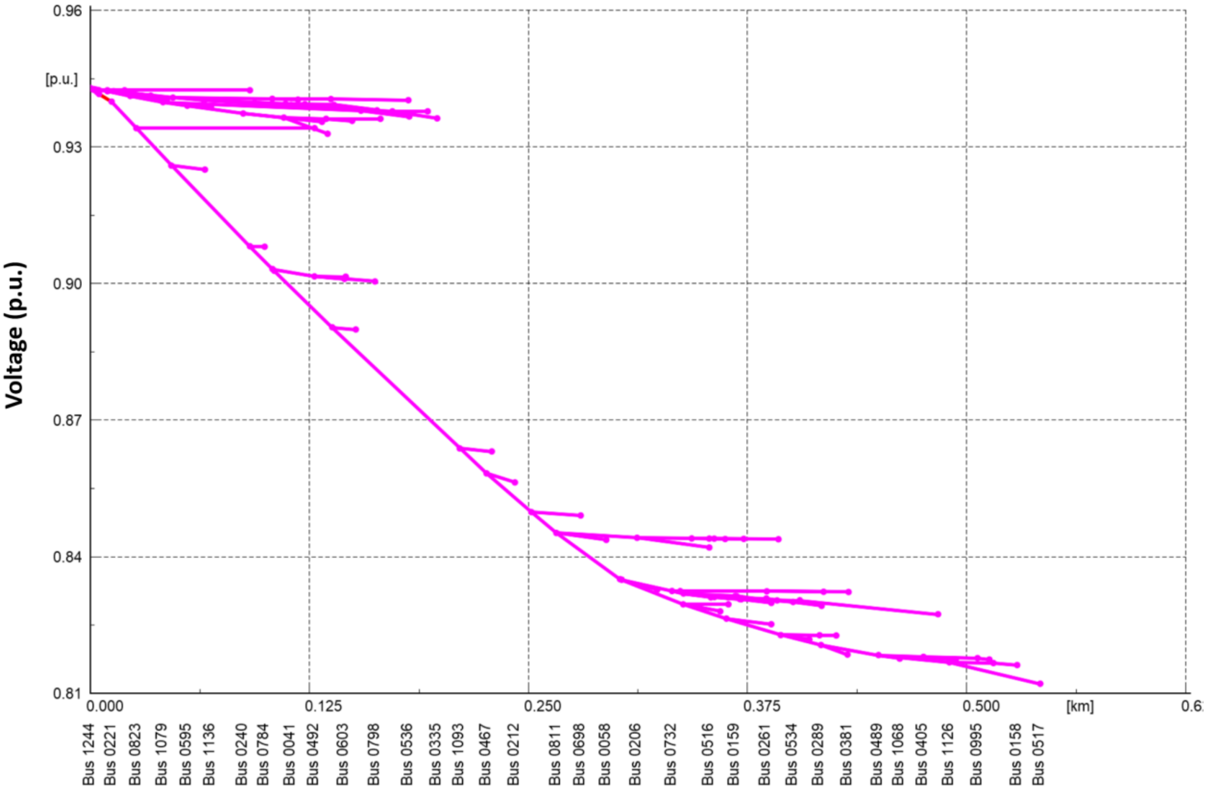

Figure 7:17: Voltage profile of Feeder 11 without any reactive support from EV chargers

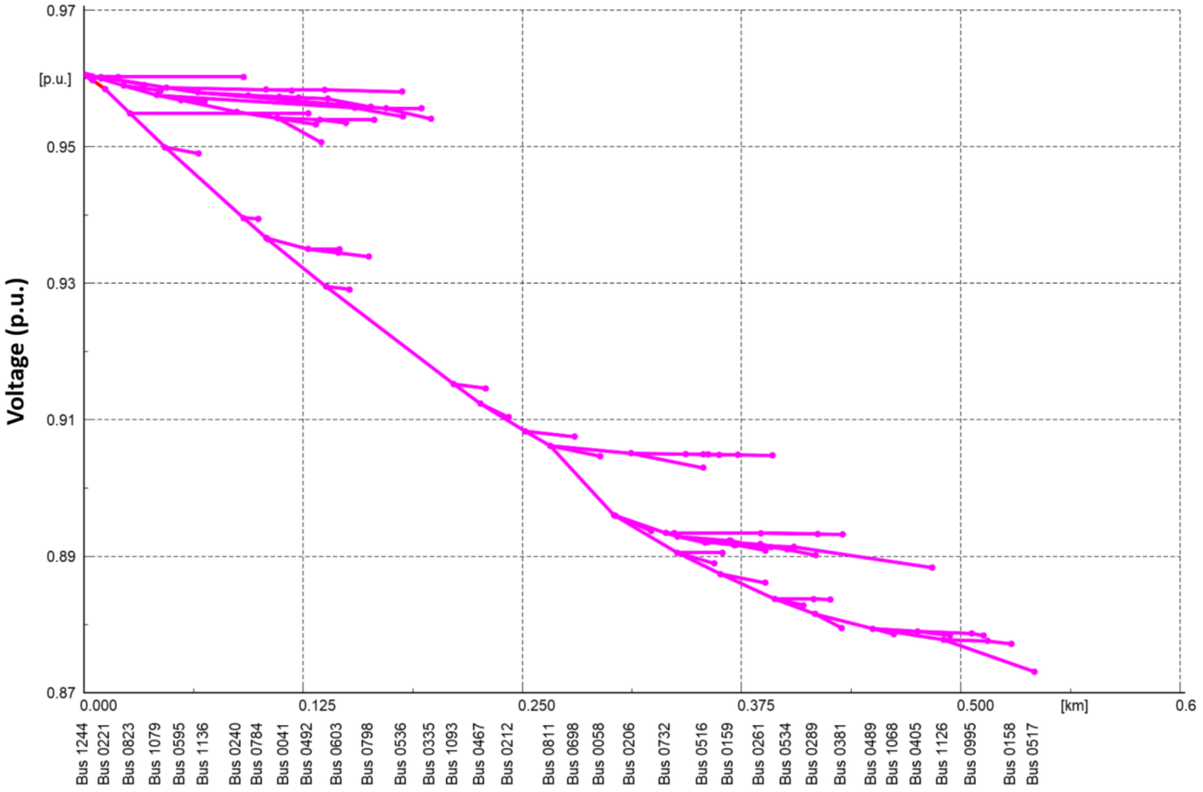

Figure 7:18: Voltage profile of Feeder 11 with reactive support from EV chargers

7.4.1.1 Analysis considering daily load characteristics

The voltage profile of the system is determined for a day by simulating the system characteristics for the load profile given in Figure 7:19. It has been assumed that each load has a power factor of 0.85. Based on these assumptions, the voltage profile for each of the different terminals in the network is illustrated in Figure 7:20(b). The figure shows that without any reactive power support from the DCFC, the voltage at one of the terminals went as low as 0.72 p.u. Additionally,from morning 6 AM, a significant number of terminals have voltages less than 0.9 p.u. The percentage of terminals that have voltages less than 0.9 p.u. or higher than 1.05 p.u. have been shown in Figure 7:21, which indicates that without any reactive power support from the DCFCs, around 25% of all terminals do not comply with the voltage limits and the voltages increase to around 30% during the evening peak periods.

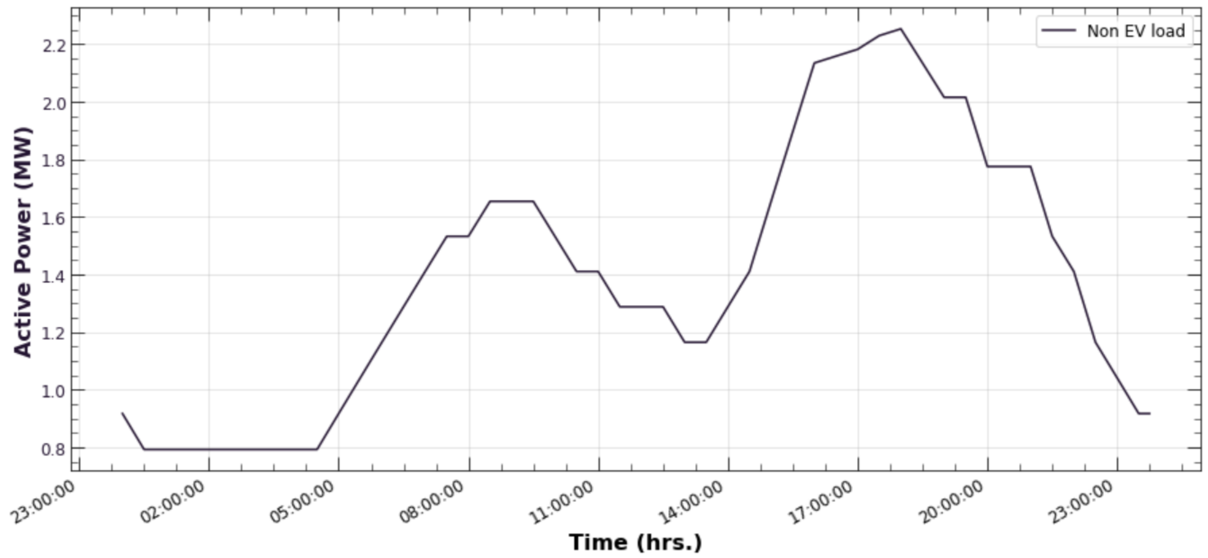

Figure 7:19: Non-EV load profile of the distribution system[80]

With reactive support from the 6 PCSs, the voltage profile of the network has improved, although some terminals still showed poor voltages, specifically during peak periods, as seen in Figure 7:20(a). Figure 7:21 shows that the percentage of terminals not complying with the voltage limits have significantly reduced, signifying the voltage profile improvement in the entire network.

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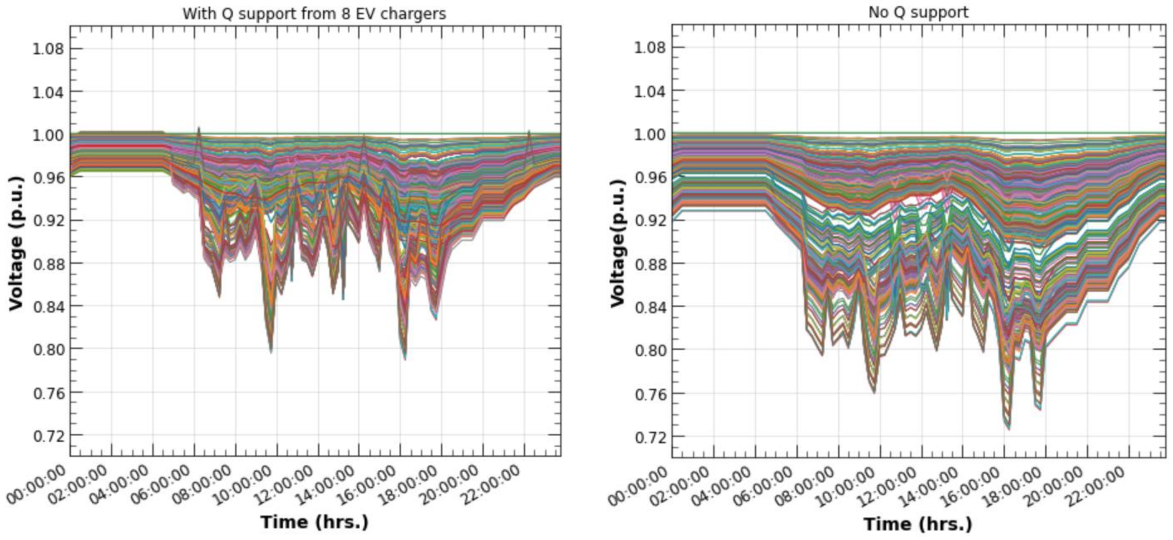
[80] The data have been collected from the Karnataka State Load Dispatch Centre and then scaled based on the distribution system.



(a) (b)

Figure 7:20: Voltage profile of each bus in the distribution network (a) with reactive support from the 8 DCFC and (b) without any support

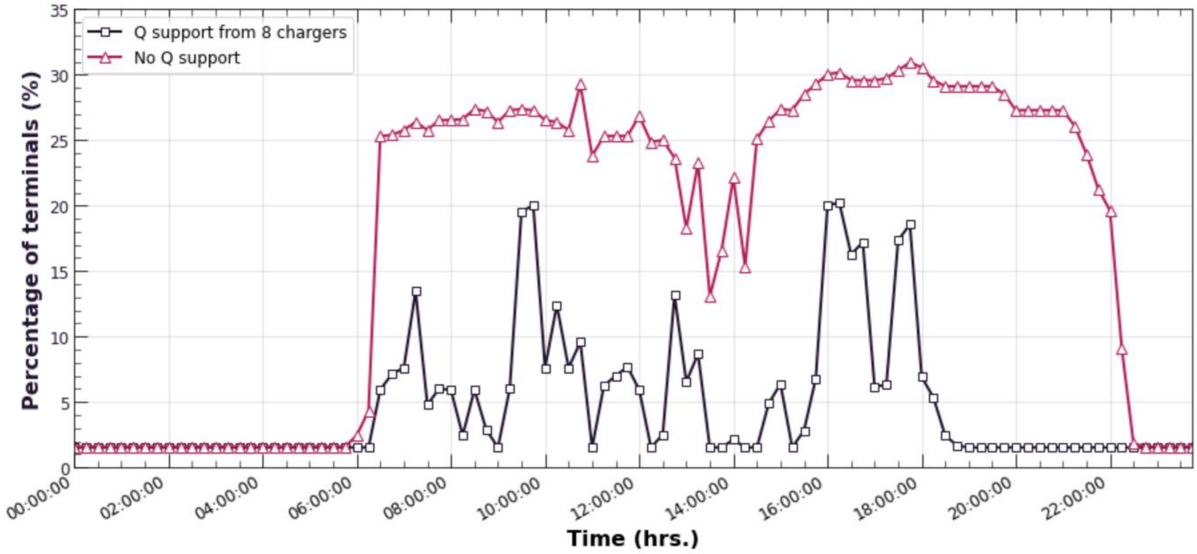


Figure 7:21: Percentage of terminals that do not comply with voltage limits of 0.9-1.05 p.u.

Figure 7:22 shows the active power drawn by the PCSs, and the voltage support offered, indicating that the PCS provided reactive power support during periods when active power was being drawn for EV charging[81]. The maximum cumulative reactive power from all the PCSs is around 600 kVAr, provided during the evening peak period duration, as shown in

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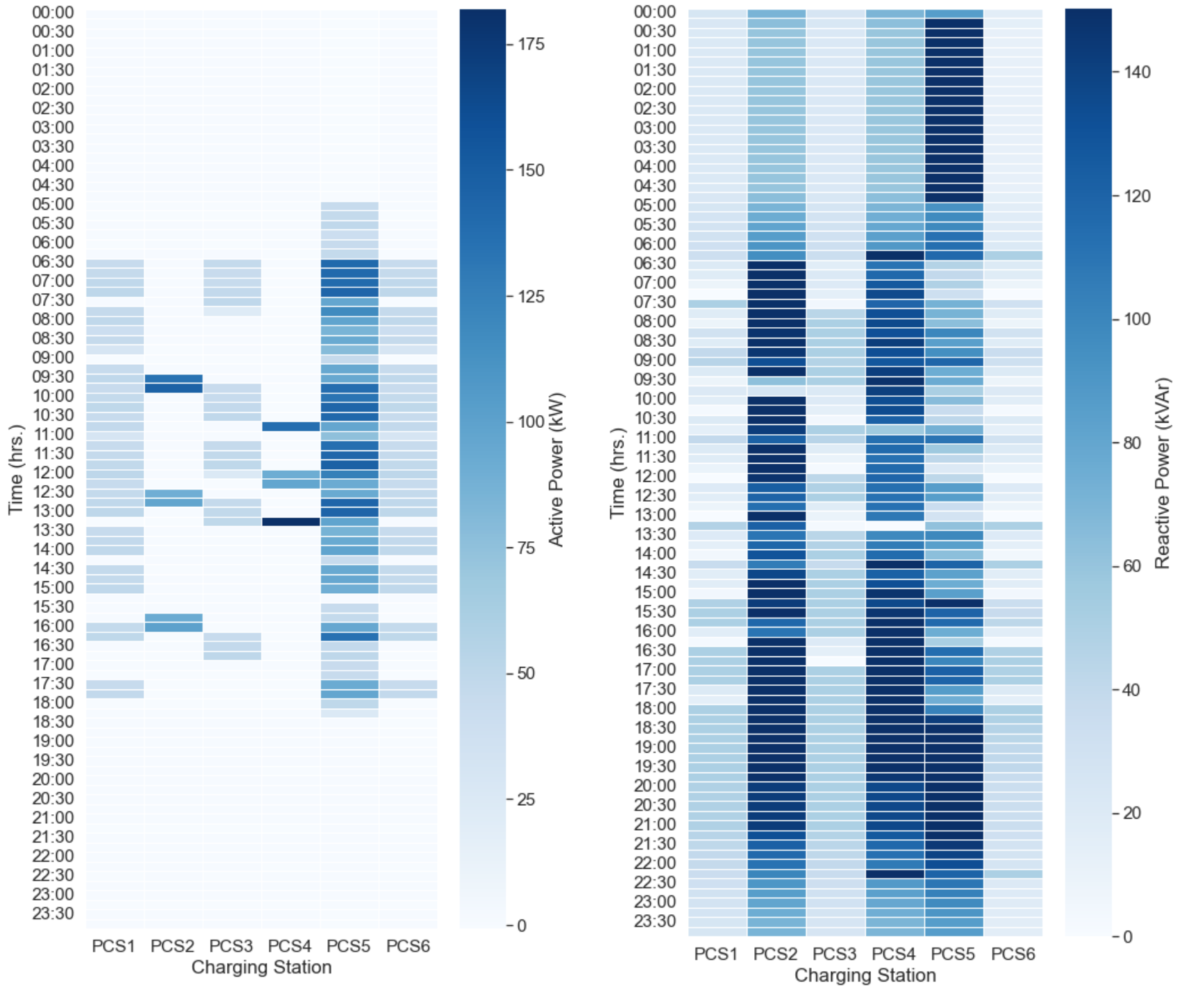
[81] The chargers could provide reactive support even while they were being used for EV charging, by oversizing the rated capacity of the converters. This logic is currently being used while sizing inverters in a solar PV plant, where the inverters are typically sized 10% larger than the maximum DC power output of the solar arrays.

Figure 7:23. The reactive power provided by the PCSs further helped reduce the consumption of reactive power from the transmission network, as highlighted in Figure 7:24. This change can potentially help in reducing/removing charges to be paid by the distribution network operator to the transmission network operator. The improvement in the voltage profile of the system also reduced the distribution losses, as shown in Figure 7:25, and can further reduce the operating costs of the network operator.



(a)

(b)

Figure 7:22: (a) Active power drawn and (b) reactive power provided by each of the different PCS

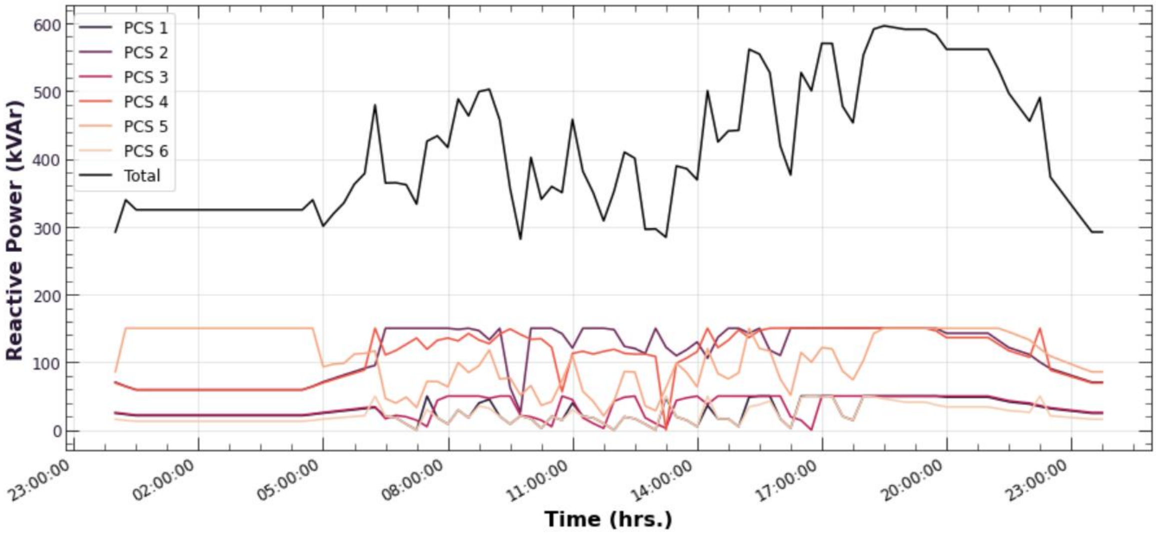


Figure 7:23: Amount of reactive power provided by the different PCS

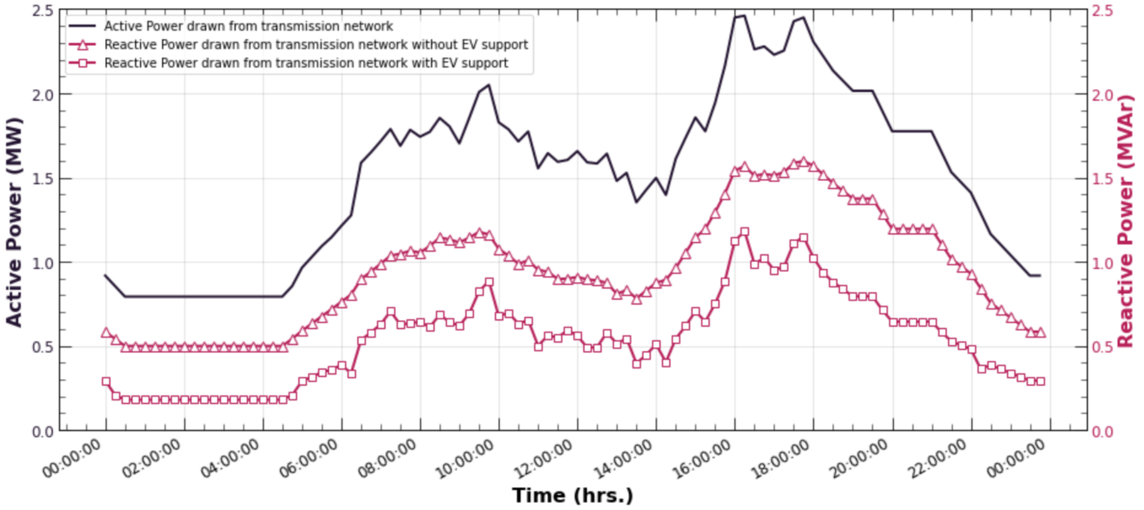


Figure 7:24: Active and reactive power drawn by the distribution network from the transmission network

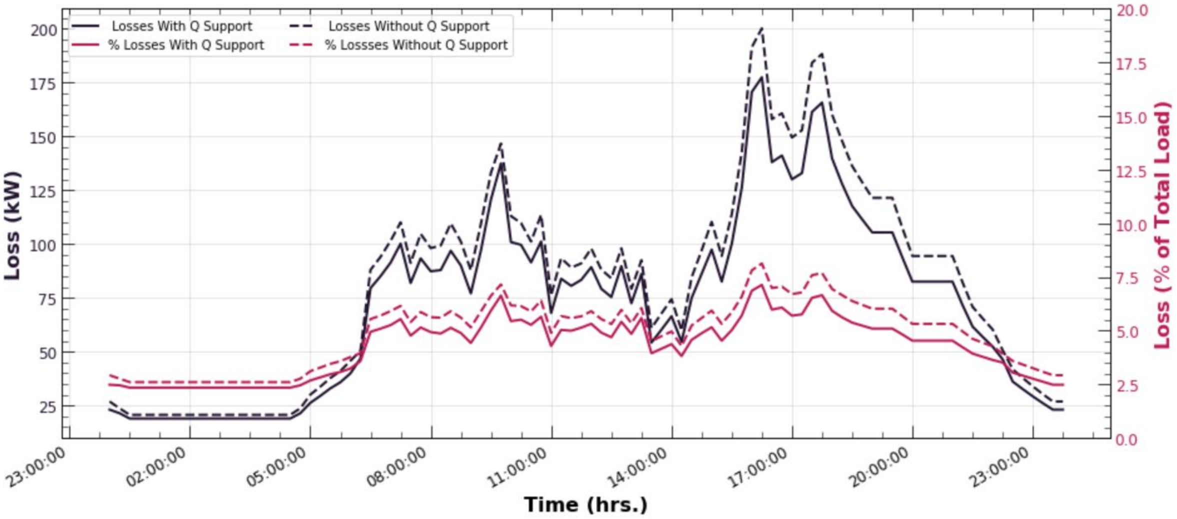


Figure 7:25: Impact of reactive support from the PCSs on the losses in the system

7.4.1.1.1 Sensitivity Analysis

The impact of reactive support from EV chargers is highly dependent on the capacity of the EV chargers as well as the location of the charging station. To illustrate this, a single high-capacity PCS, as described in Section 7.2.2, has been installed at the 11 kV feeder of the network instead of six distributed PCSs. Although the cumulative rated capacity of the single PCS is larger than the six distributed PCSs, it had a lesser impact on improving the voltage levels of the different terminals of the network, as shown in Figure 7:26.

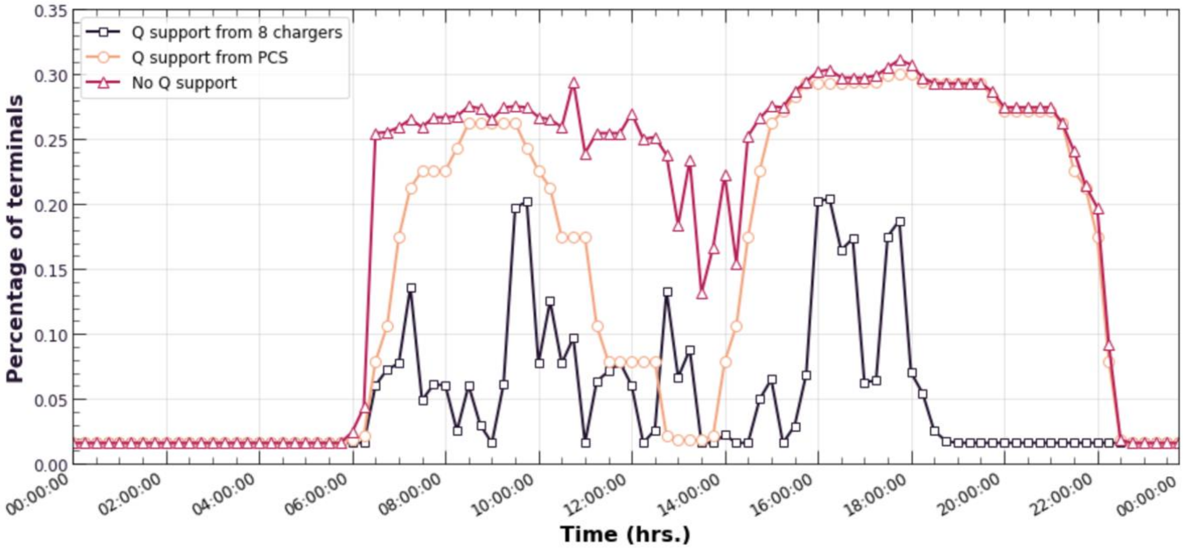
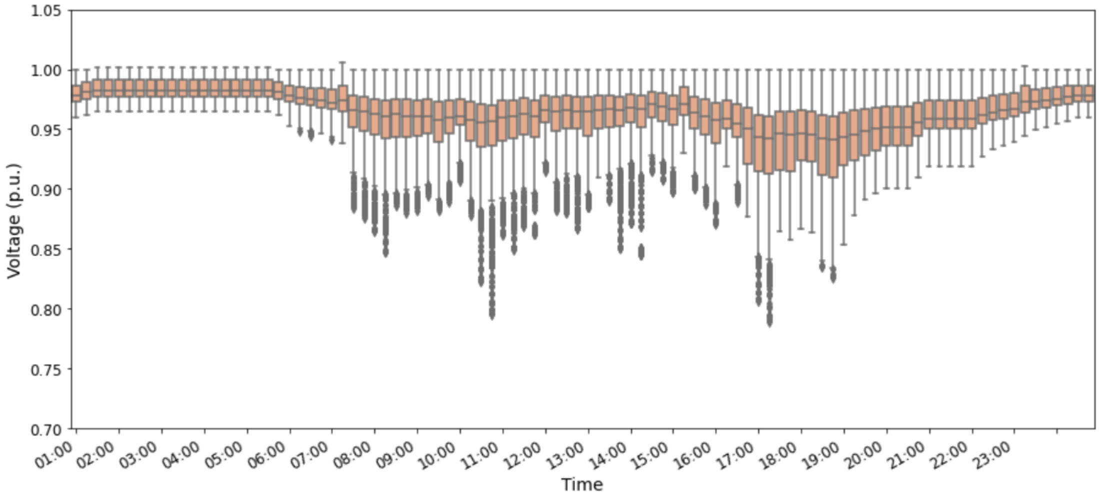
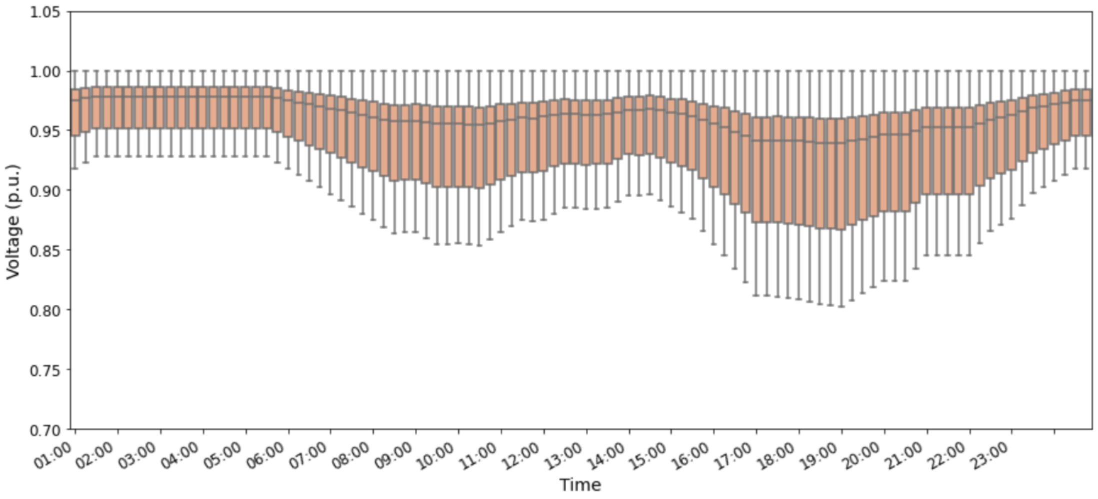


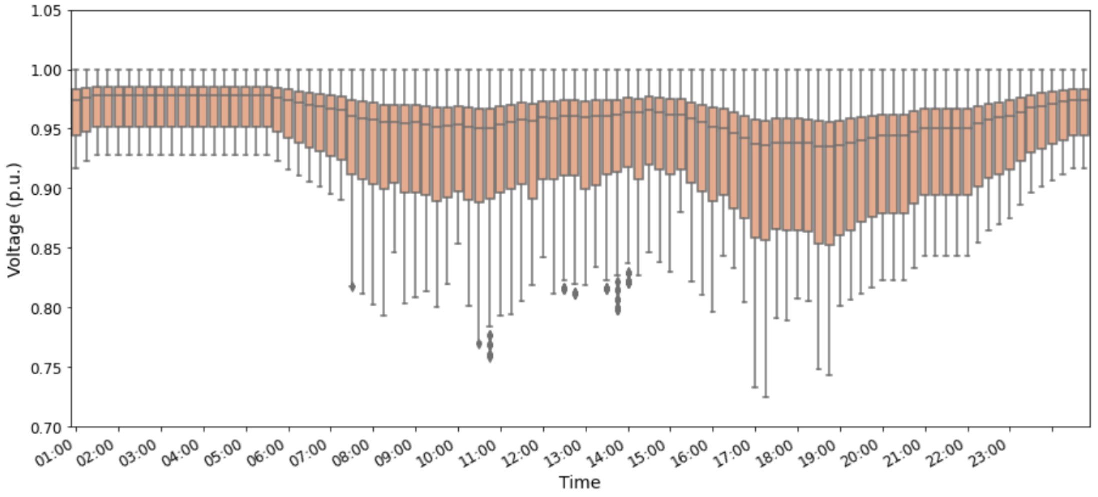
Figure 7:26: Percentage of terminals that doesn't comply with voltage limits of 0.9-1.05 p.u



(a)



(b)



(c)

Figure 7:27: Boxplot showing voltage variations in all the buses of the network for (a) Reactive support from 6 distributed PCS, (b) Reactive support from 1 large PCS, (c) No reactive support

The voltage variations in the entire network have been described in Figure 7:27, which shows that with reactive power support from the six distributed PCS, voltages of most of the terminals are contained within 0.9 p.u. However, there were still some terminals whose voltages breached the limit of 0.9 p.u. as denoted by the outliers. With reactive power support from the single large PCS, the outliers are significantly reduced, implicating that the reactive support was able to impact the voltages of most of the feeders. However, the impact was less compared to the distributed PCSs as the number of terminals with voltages below 0.9 p.u. reduced.

The total consumption of reactive power from the transmission network is shown in Figure 7:28, which shows that even though the rated reactive power support capability of the large

PCS is 850 kVAr and the cumulative reactive power capability of the six distributed PCSs is 600 kVAr, the six PCSs are able to provide a higher amount of reactive power support to the distribution network. The distributed PCSs can better reduce the distribution network's reactive power dependency on the transmission network while also minimizing the losses in the system, as shown in Figure 7:29. The daily losses in the system are highest when support is provided by one large PCS, as shown in Figure 7:30, which can be attributed to the fact that although the reactive power flow had increased compared to the case when no support was provided, the voltages of the terminals did not improve significantly, i.e., the reduction in losses due to improvement in voltage profile was lesser compared to the increase in losses due to increased reactive power flow. However, with the distributed PCS, the losses in the system were the least, implying that the reduction in losses due to improvement in voltage profile was much higher compared to the increase in losses due to increased reactive power flow.

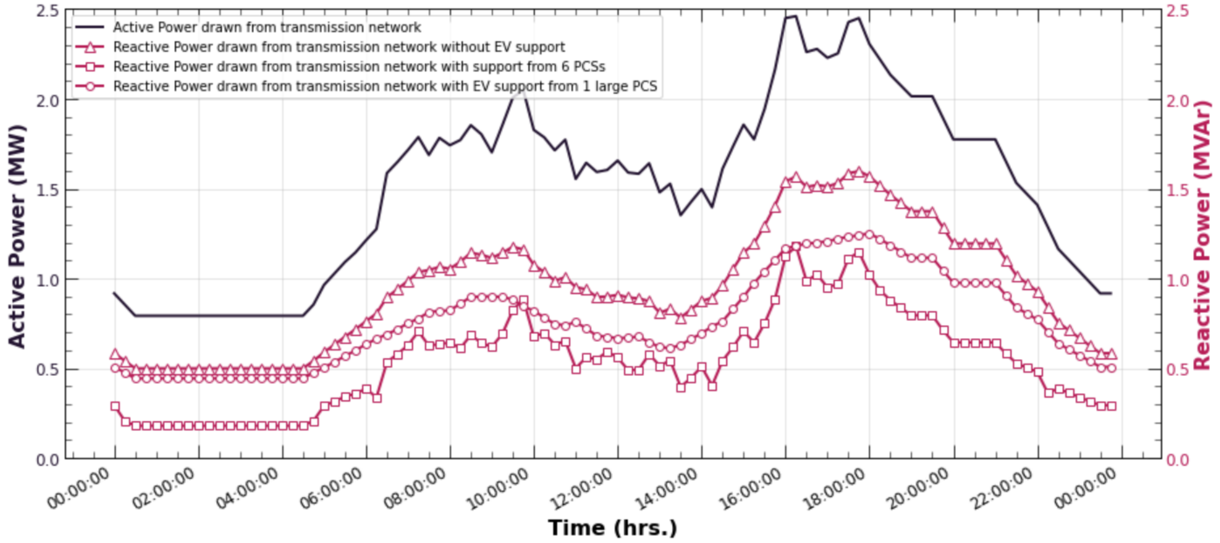


Figure 7:28: Active and reactive power drawn by the distribution network from the transmission network

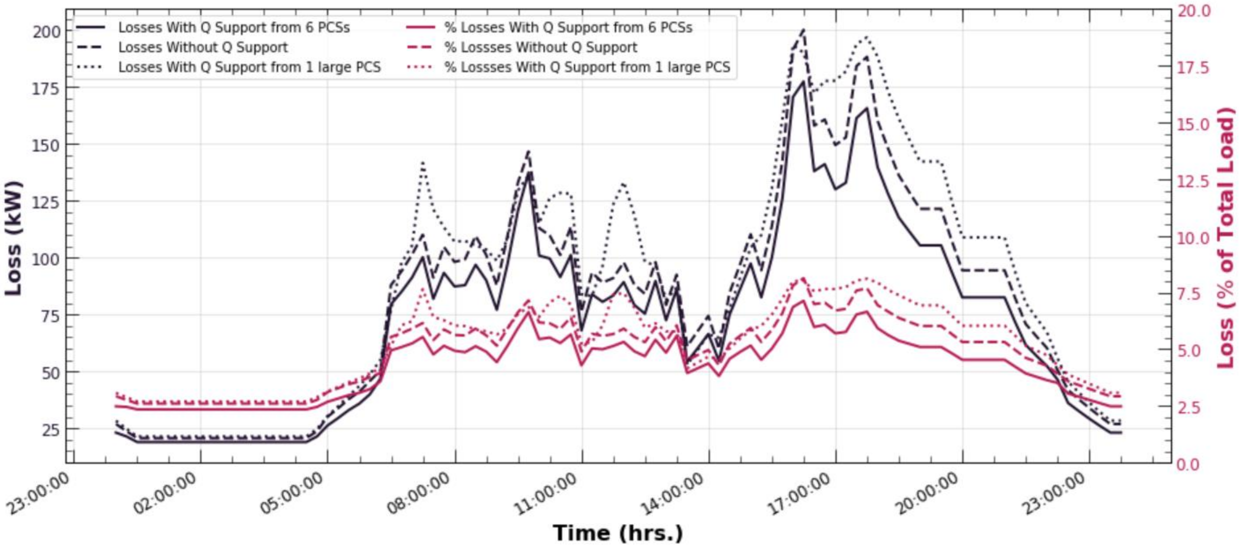


Figure 7:29: Losses in the distribution network for the different cases

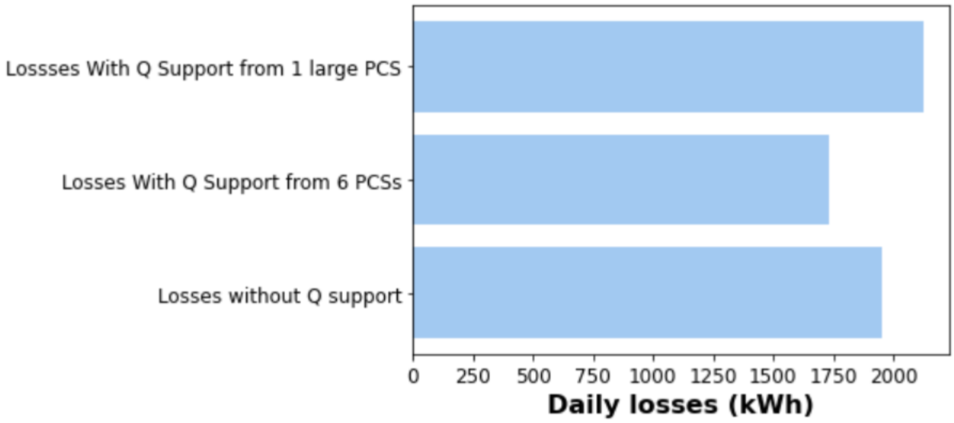


Figure 7:30: Daily losses in the distribution network

7.4.1.2 Analysis considering annual load characteristics

The effect of seasons may also impact the voltage support requirements of the network and the reactive support from EVs. For this analysis, representative load curves have been taken for all the months of the year from the Delhi State Load Dispatch Centre and scaled based on the total load in the system. The representative annual load curve is shown in Figure 7:31, from which the electrical load is generally higher during the summer months of June, July and August. Also, a difference in the load pattern can be observed. During November, December, January, February and March, the nighttime has considerably lesser loads and can be considered off-peak periods. On the contrary, during June, July and August, the nighttime has a considerable load compared to the peak periods.

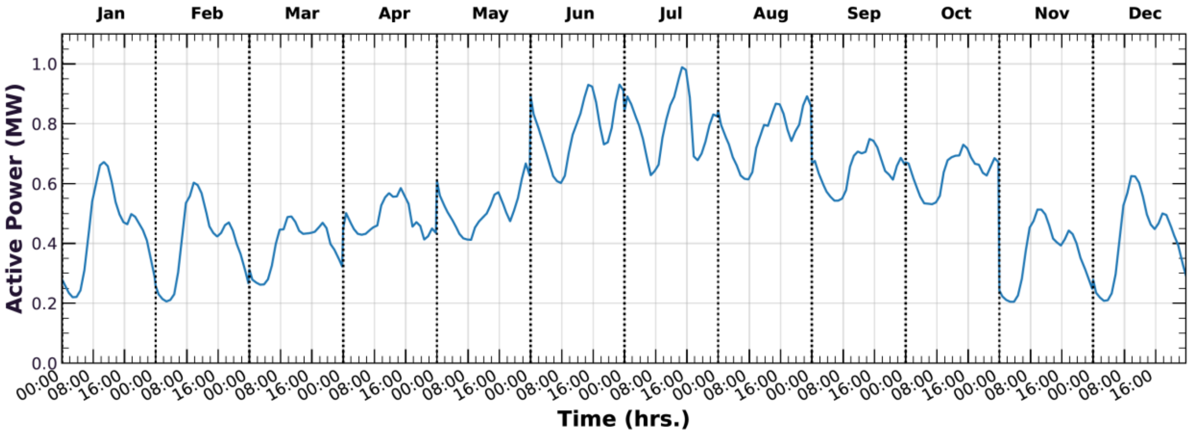
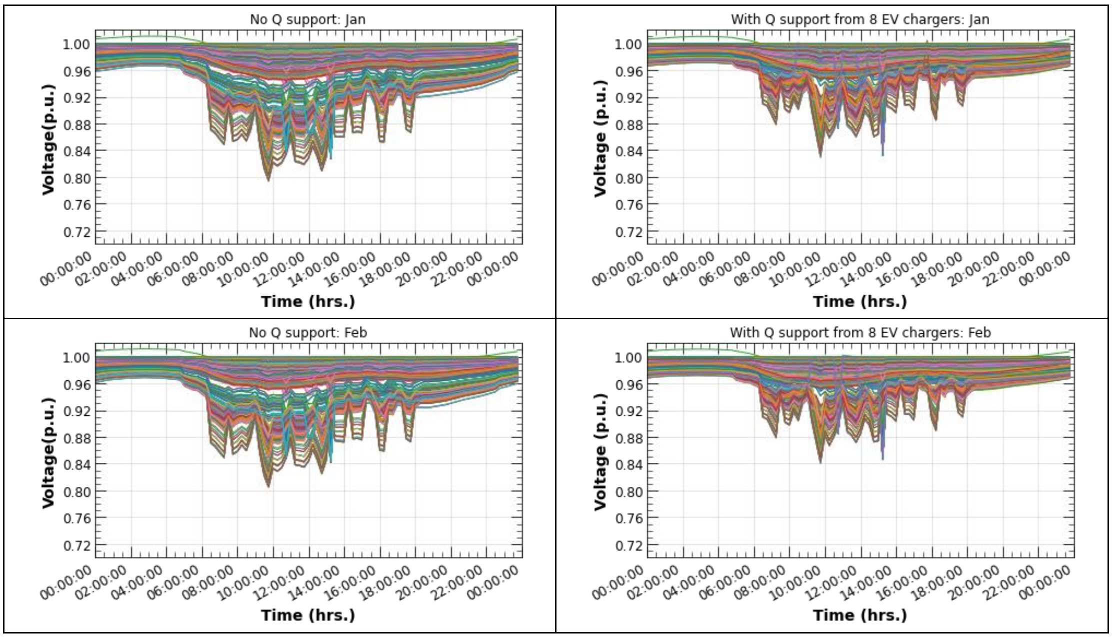
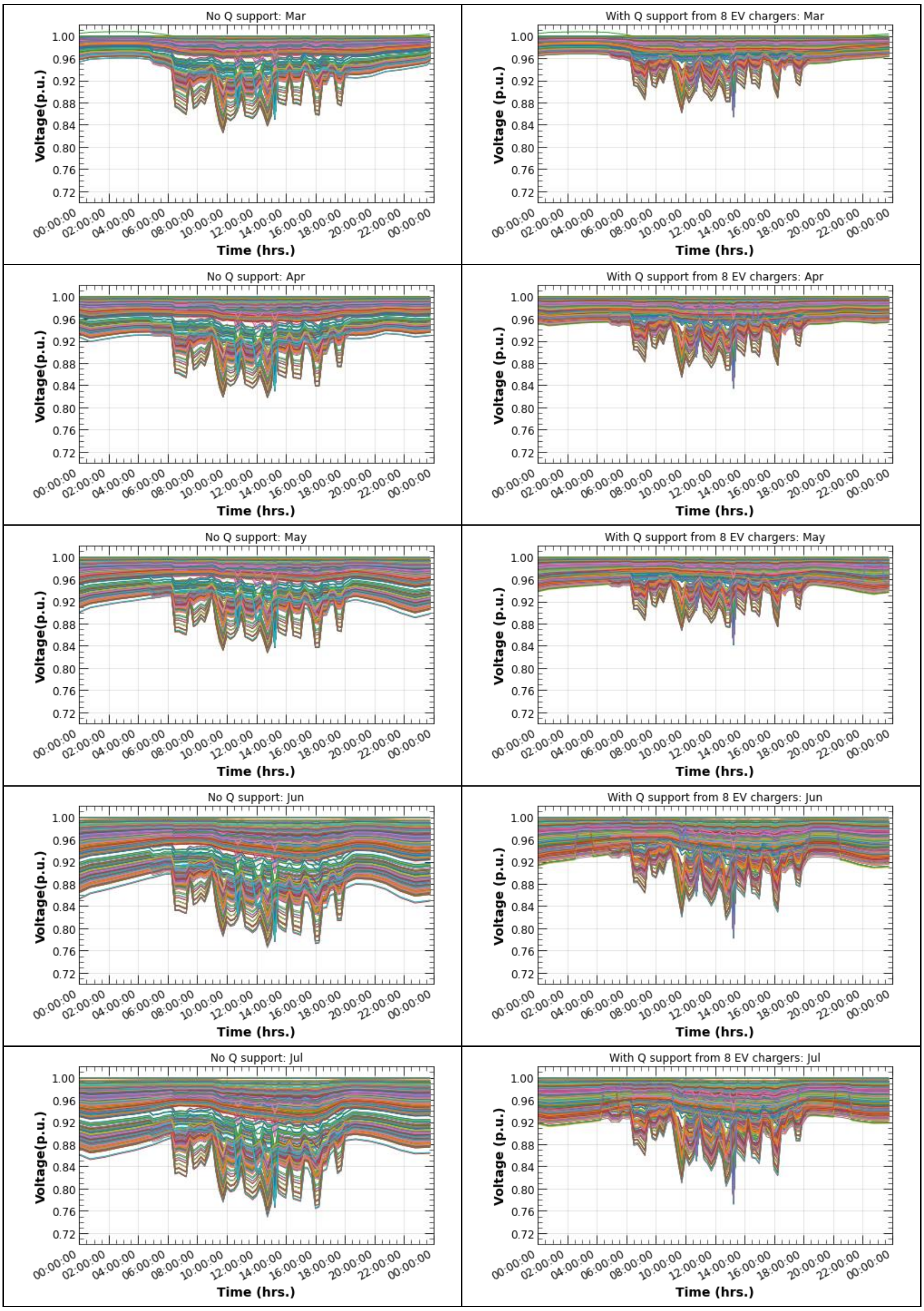


Figure 7:31: Non-EV load curve considered for annual analysis (For each month, a representative daily load curve has been considered)

The resulting voltage profile of the network is shown in

Figure 7:*32*, which shows that the voltage profile of the network is significantly poor during June, July and August, where some buses always have a voltage of less than 0.9. With the addition of reactive support from PCS, the voltage profile of many buses improves, specifically during night periods, where the entire capacity of the PCS is generally available to provide reactive power to the network. The reactive power support provided by each PCS is shown in Figure 7:33. In this analysis, it has been considered that the non-EV loads have a power factor of 0.95. Considering that the non-EV loads have a power factor of 0.9, the voltage profile of the network further deteriorates, as shown in Figure 7:34, where during certain periods in July and August, some of the buses reached a voltage level of 0.72 p.u.




No Q support: Mar
With Q support from 8 EV chargers: Mar
No Q support: Apr
With Q support from 8 EV chargers: Apr
No Q support: May
With Q support from 8 EV chargers: May
No Q support: Jun
With Q support from 8 EV chargers: Jun
No Q support: Jul
With Q support from 8 EV chargers: Jul
Voltage(p.u.)
Voltage (p.u.)
1.00
0.96
0.92
0.88
0.84
0.80
0.76
0.72
00:00:00
02:00:00
04:00:00
06:00:00
08:00:00
10:00:00
12:00:00
14:00:00
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20:00:00
22:00:00
00:00:00
Time (hrs.)

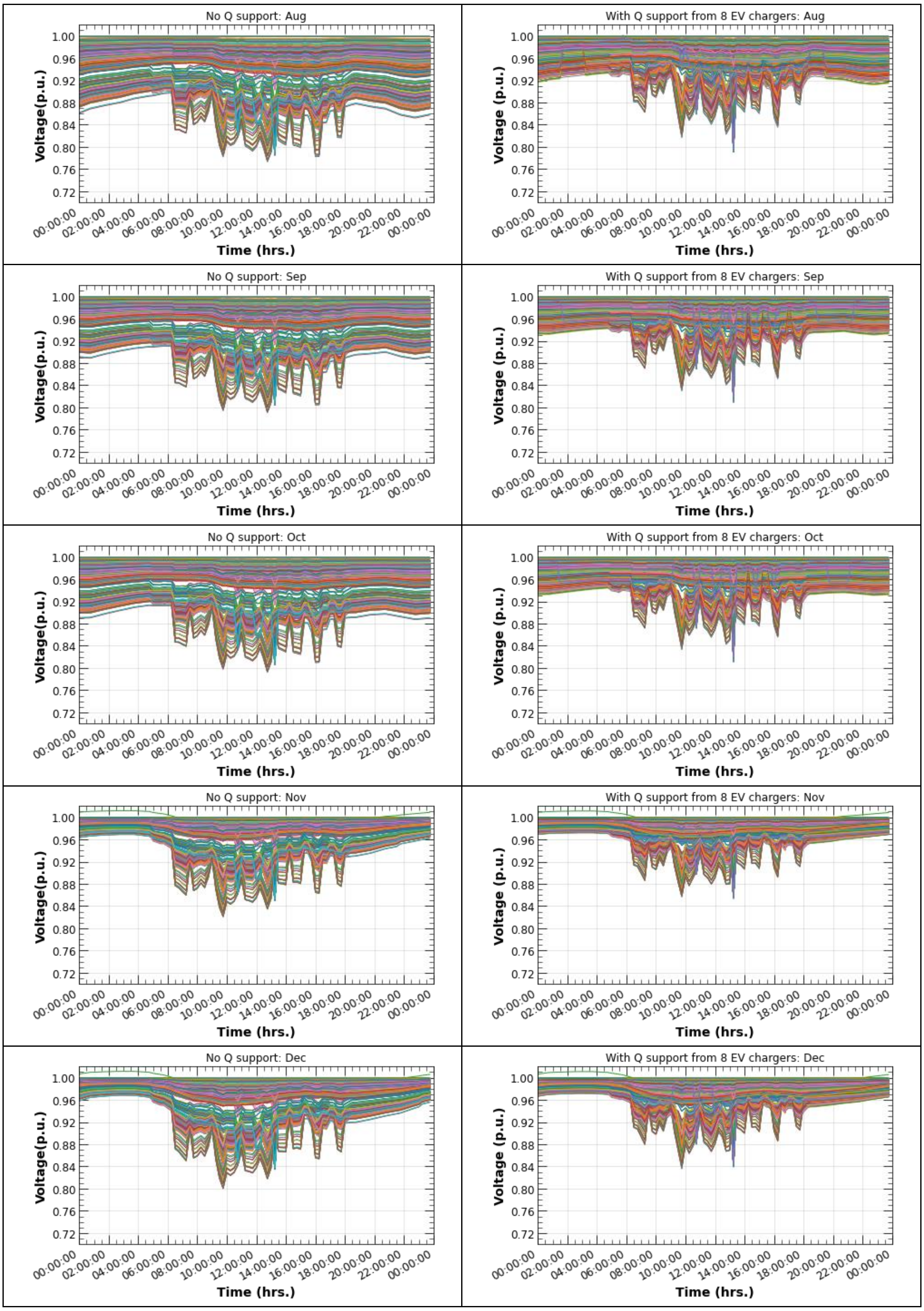


Figure 7:32: Voltage profile of each bus in the network shown for each month of the year, with and without reactive support from EVs, considering each non-EV load has a power factor of 0.95

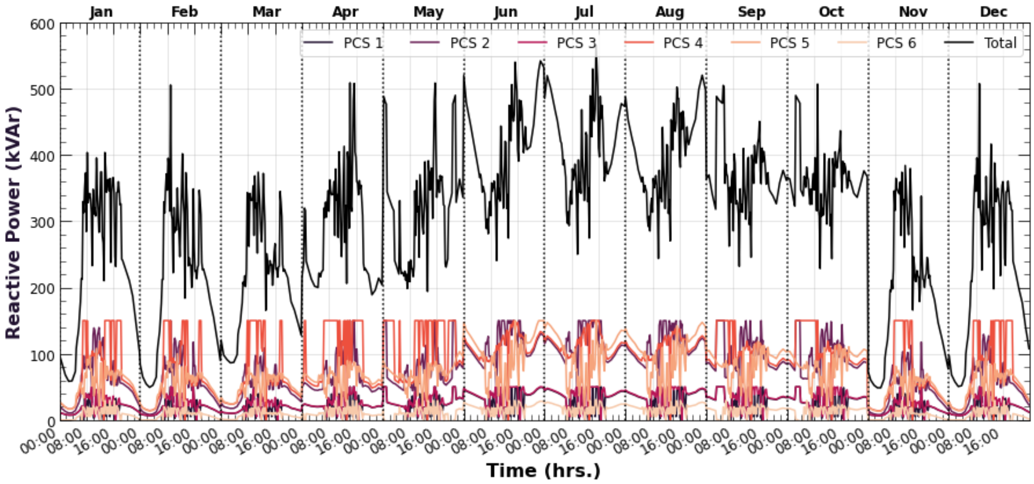
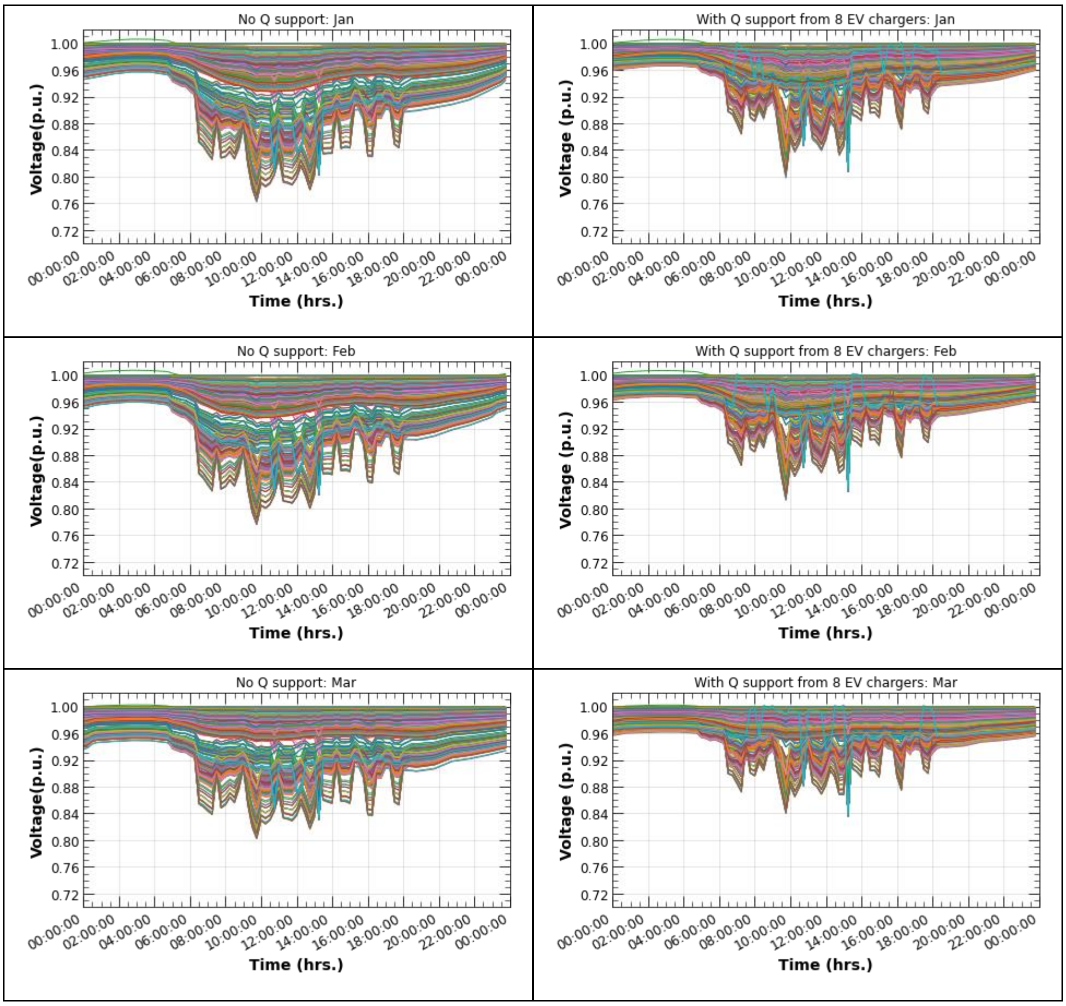
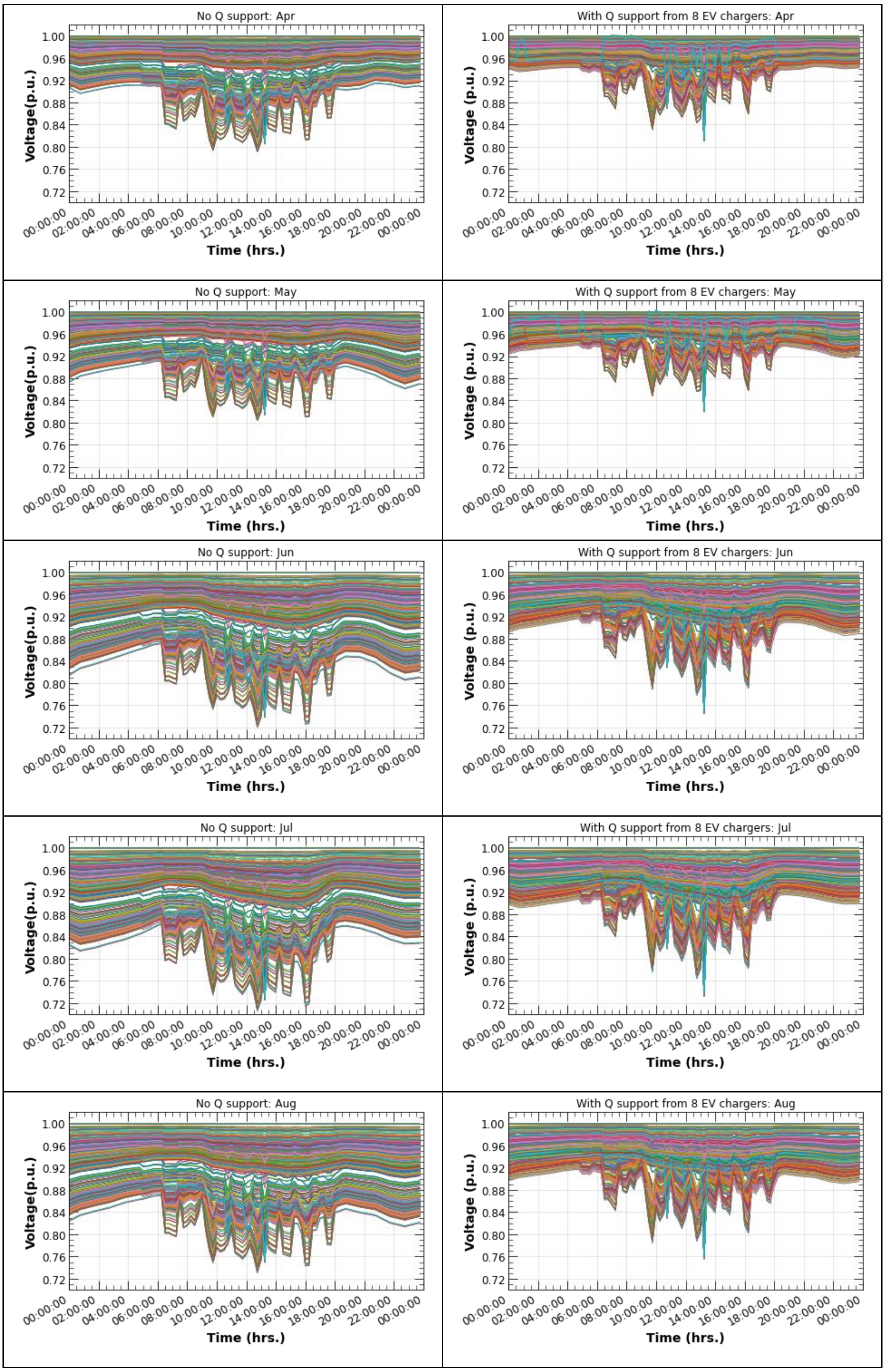


Figure 7:33: Reactive power support from the different PCSs, considering each non-EV load has a power factor of 0.95




No Q support: Apr
With Q support from 8 EV chargers: Apr
No Q support: May
With Q support from 8 EV chargers: May
No Q support: Jun
With Q support from 8 EV chargers: Jun
No Q support: Jul
With Q support from 8 EV chargers: Jul
No Q support: Aug
With Q support from 8 EV chargers: Aug
Voltage(p.u.)
Voltage (p.u.)
1.00
0.96
0.92
0.88
0.84
0.80
0.76
0.72
00:00:00
02:00:00
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20:00:00
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00:00:00
Time (hrs.)

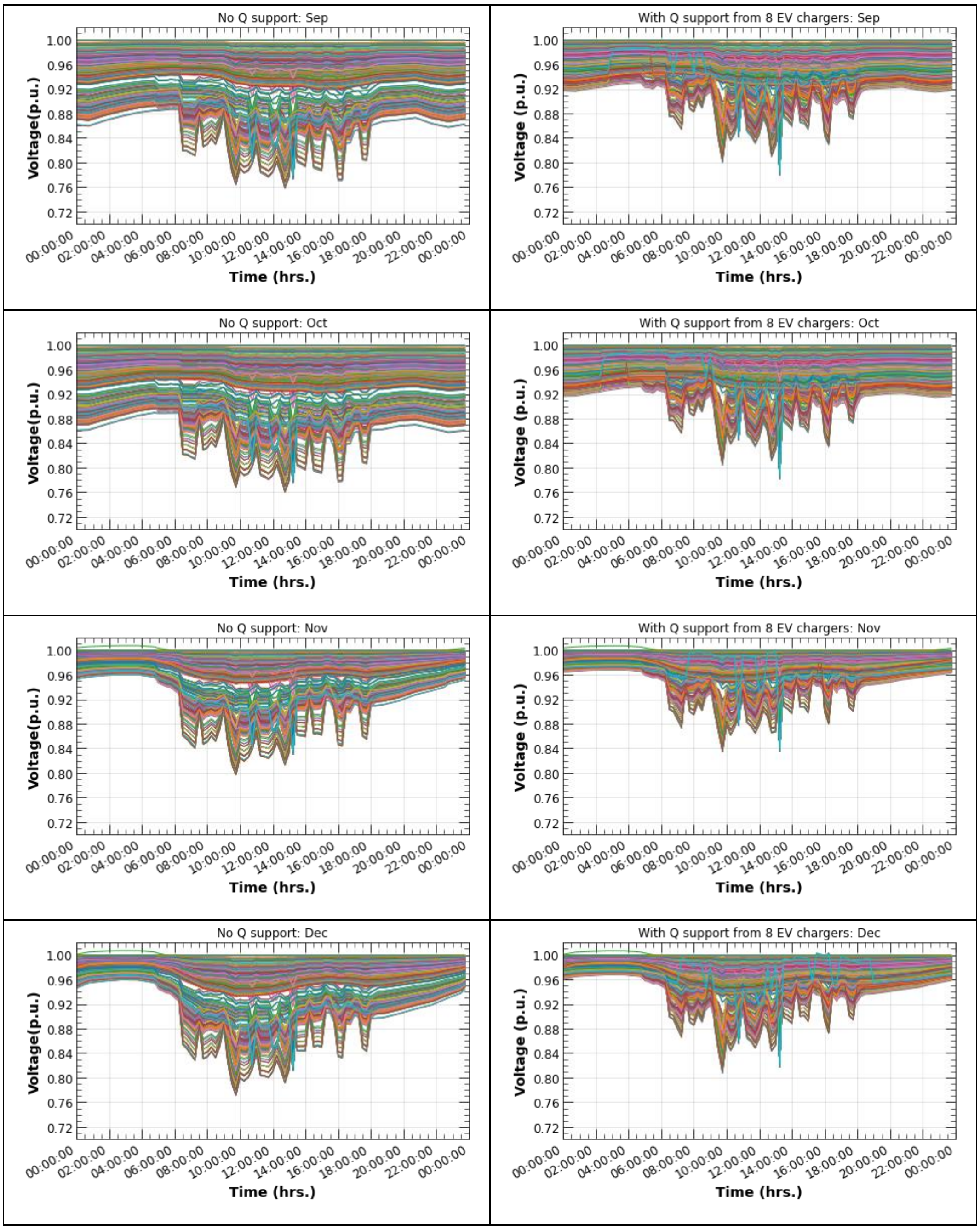


Figure 7:34: Voltage profile of each bus in the network shown for each month of the year, with and without reactive support from EVs, considering each non-EV load has a power factor of 0.9

The percentage of buses that do not comply with the voltage thresholds of 0.9-1.1 p.u. have been illustrated in Figure 7:35 and Figure 7:36 for power factors of 0.95 and 0.9, respectively, for non-EV loads. As seen in both scenarios, reactive power support from PCS significantly reduces the number of buses that do not comply with the minimum voltage requirements, with the improvement being much more significant when the reactive power consumed by the non-EV loads is higher.

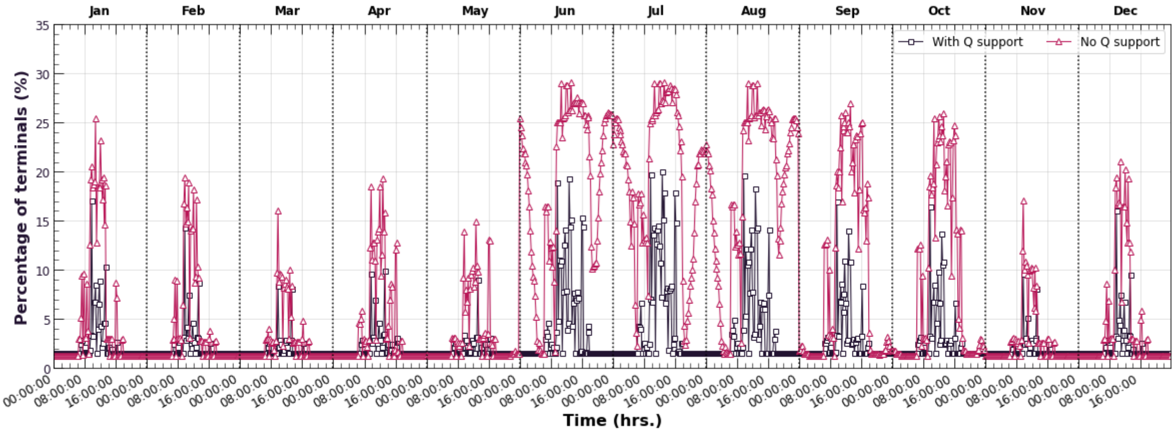


Figure 7:35: Percentage of terminals that do not comply with voltage limits of 0.9-1.05 p.u, considering non-EV loads to have a power factor of 0.95

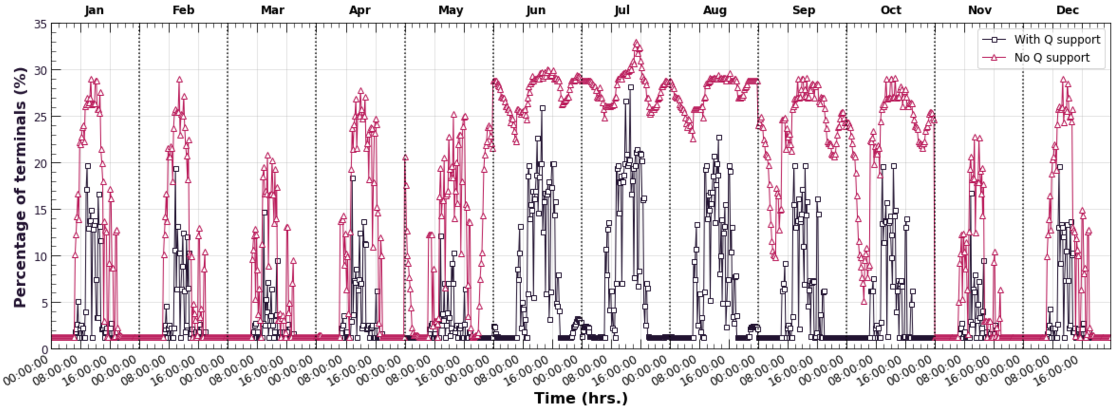


Figure 7:36: Percentage of terminals that do not comply with voltage limits of 0.9-1.05 p.u, considering non-EV loads to have a power factor of 0.9

The resulting loss in the transmission and distribution of power in the distribution network has been shown in Figure 7:39, Figure 7:38 and Figure 7:39, from which it can be seen that the losses are again higher during the high load periods of the summer months. The reduction in losses due to reactive power support from EVs is again more pronounced for the scenario when the non-EV loads have a power factor of 0.9.

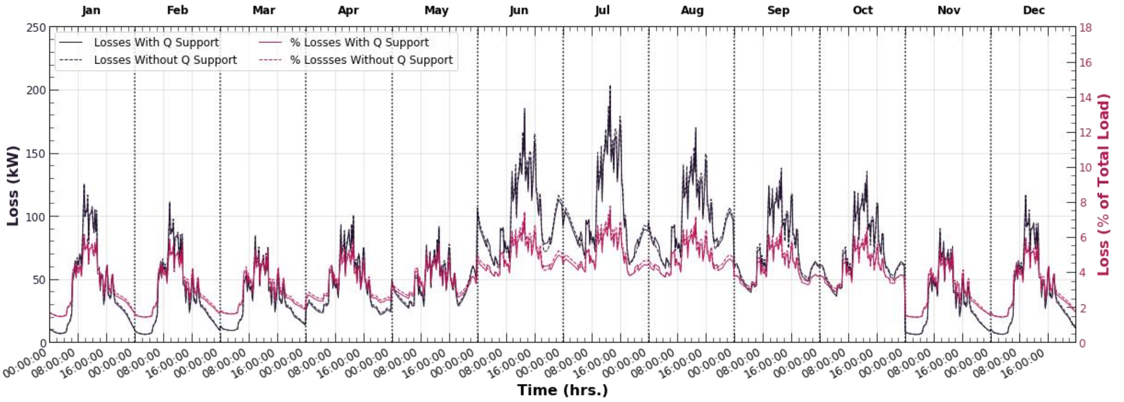


Figure 7:37: Losses in the network when non EV loads have power factor of 0.95

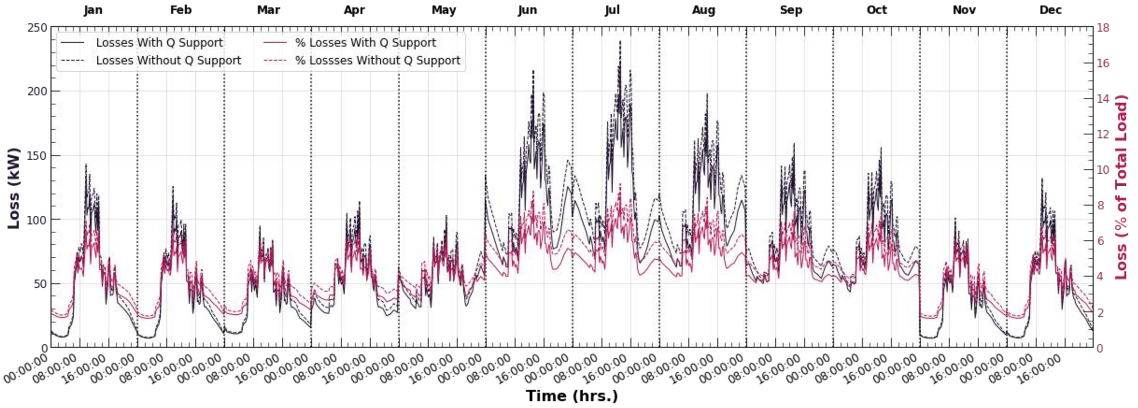
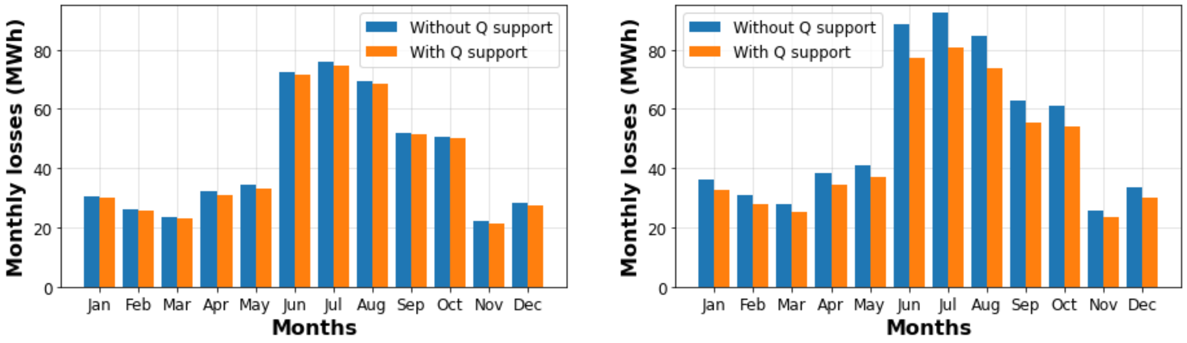


Figure 7:38: Losses in the network when non EV loads have power factor of 0.9



(a)

(b)

Figure 7:39: Monthly transmission and distribution losses for (a) non EV load power factor of 0.95 and (b) non EV load power factor of 0.9

7.4.1.3 Cost Benefit Analysis

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 transmission network

- Cost savings due to reduced losses in the system

7.4.1.3.1 Reduced reactive power drawal from the transmission network

The Indian Grid Code 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 drawal, the following reward/incentive scheme has been adopted in India,

- The regional entity pays for VAr drawal when the voltage at the interconnection point is below 0.97 p.u.
- The regional entity gets paid for VAr injection when the voltage at the interconnection point is below 0.97 p.u.
- The regional entity gets paid for VAr drawal when the voltage at the interconnection point is above 1.03 p.u.
- The regional entity pays for VAr injection when the voltage at the interconnection point is above 1.03 p.u.

In line with IEGC, charges for VArh considered in this case study are INR 0.16/kVArh, and therefore, the benefits of reactive power support from EVs have been determined accordingly. Since the network has been modelled only up to the 11 kV voltage level and the interconnection with the transmission network has been represented as an external grid element, the voltage at the point of interconnection has been considered 0.965 p.u. The total reactive power drawn from the transmission network has been shown in Figure 7:40 and Figure 7:41 for the two scenarios considered. For both the scenarios, the net drawal of reactive power from the transmission network decreases when PCS is being used to provide reactive support. The monthly penalty incurred by DISCOM is given in Figure 7:42. The Draft Indian Grid Code 2022 has significantly reduced the penalty incurred due to reactive power drawal, as seen in Figure 7:42. The total annual savings that can be attained by the DISCOM by utilising the reactive power support from PCS is given in Figure 7:43. As seen under the existing Indian Grid Code 2010, the DISCOM can save INR 3-4 Lakh (EUR 3,550 – 4,725) annually.

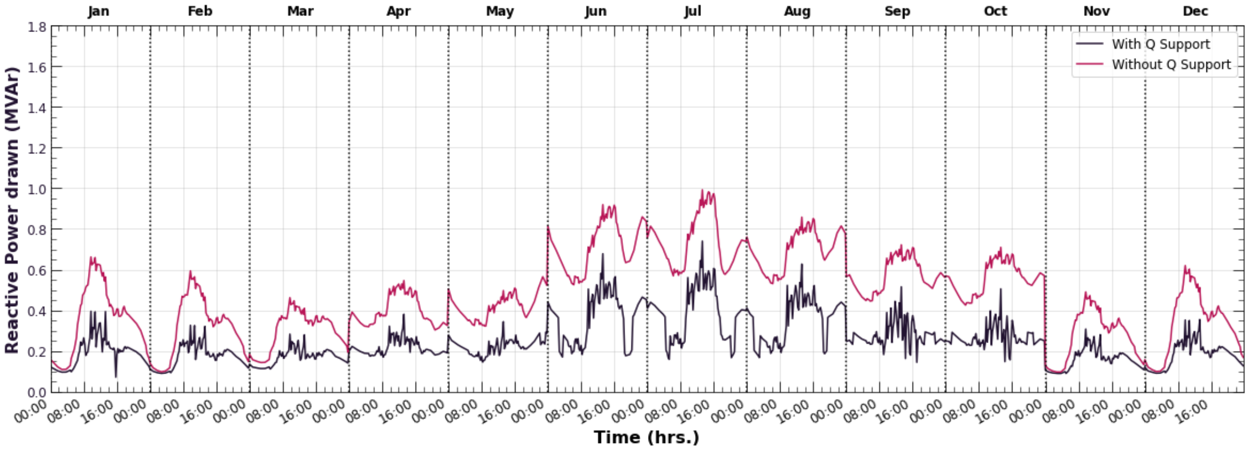


Figure 7:40: Reactive power drawn from the transmission network with and without reactive power support from EVs, when non EV loads have a power factor of 0.95

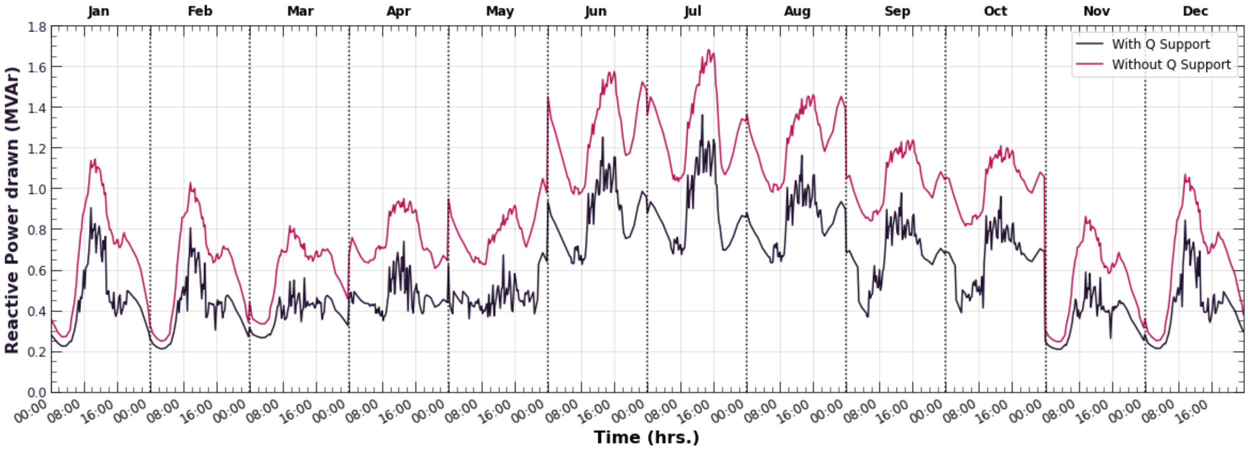
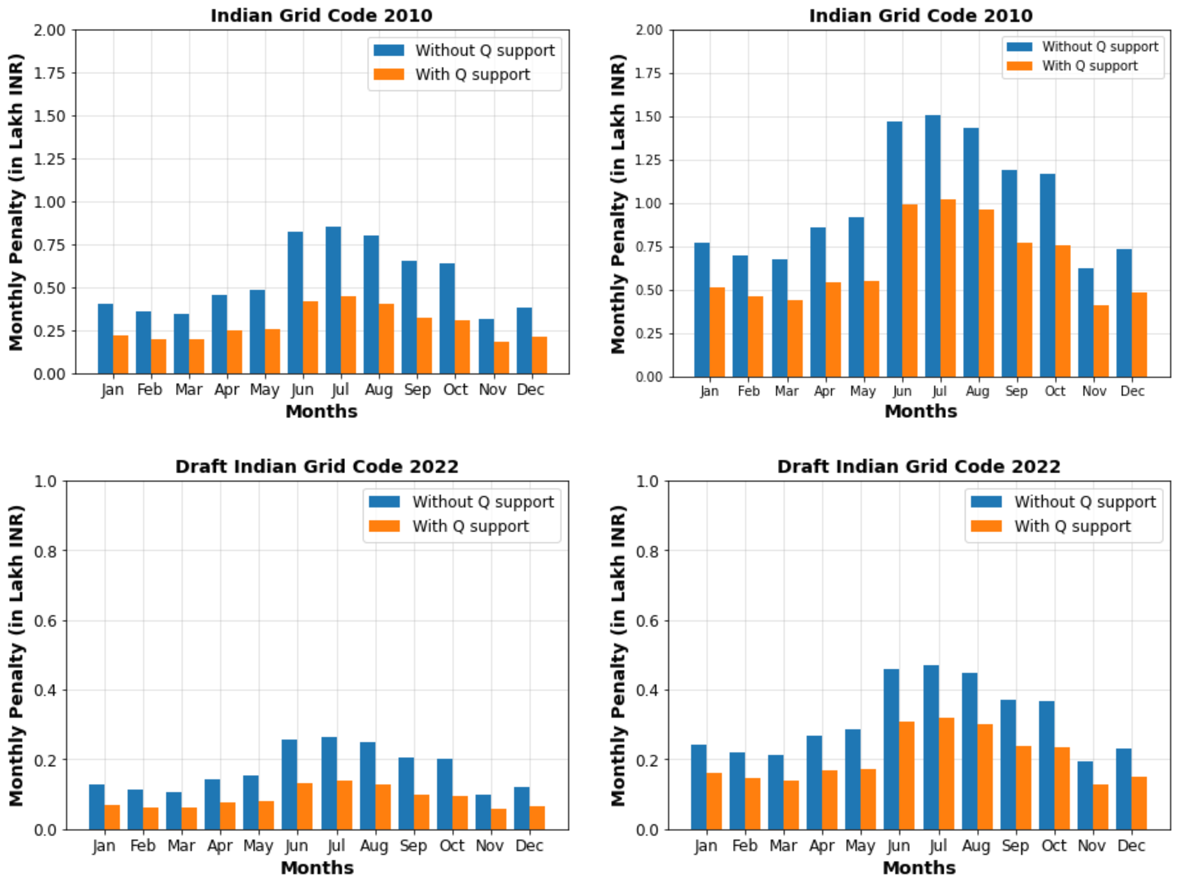


Figure 7:41: Reactive power drawn from the transmission network with and without reactive power support from EVs, when non EV loads have a power factor of 0.9



(a)

(b)

Figure 7:42: The monthly penalty imposed on the DISCOM for drawal of reactive power from the transmission network shown for (a) non EV loads have power factor of 0.95 and (b) non EV loads have power factor of 0.9

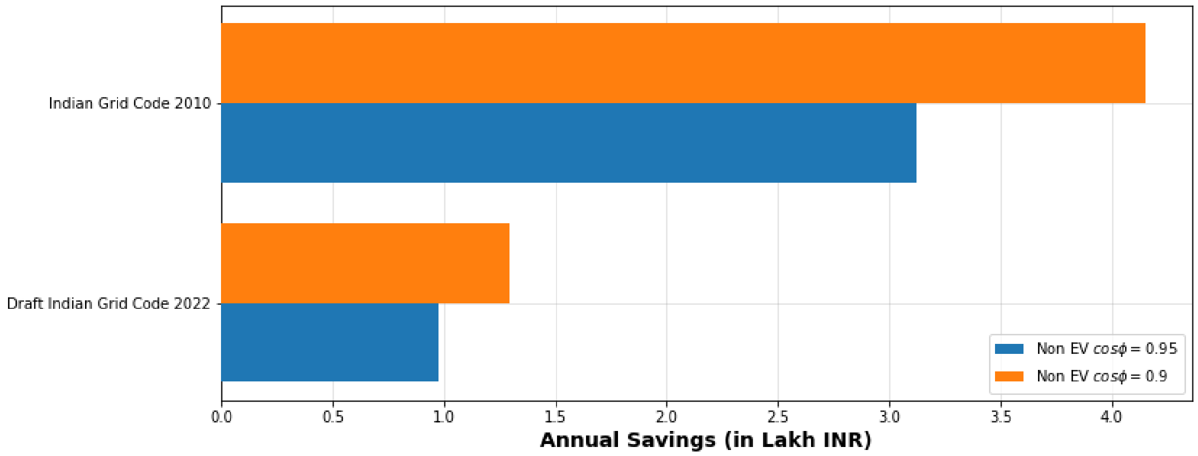


Figure 7:43: Annual savings when providing reactive power support from PCS

7.4.1.3.2 Reduced losses in the system

The reactive support from the PCS also helped in reducing the losses in the system. The average Cost of Supply of electricity in Delhi as per the tariff order of 2021-2022 is around INR 7.4/kWh. Hence, assuming that the network operator has to pay this amount for the losses in the system, the cost analysis has been presented in Figure 7:44 and Figure 7:45. The annual savings due to a reduction in transmission and distribution losses are around INR 5,22,173 (EUR 6,168) when the non-EV loads have a power factor of 0.9 and INR 70,103 (EUR 828) when the power factor is 0.95.

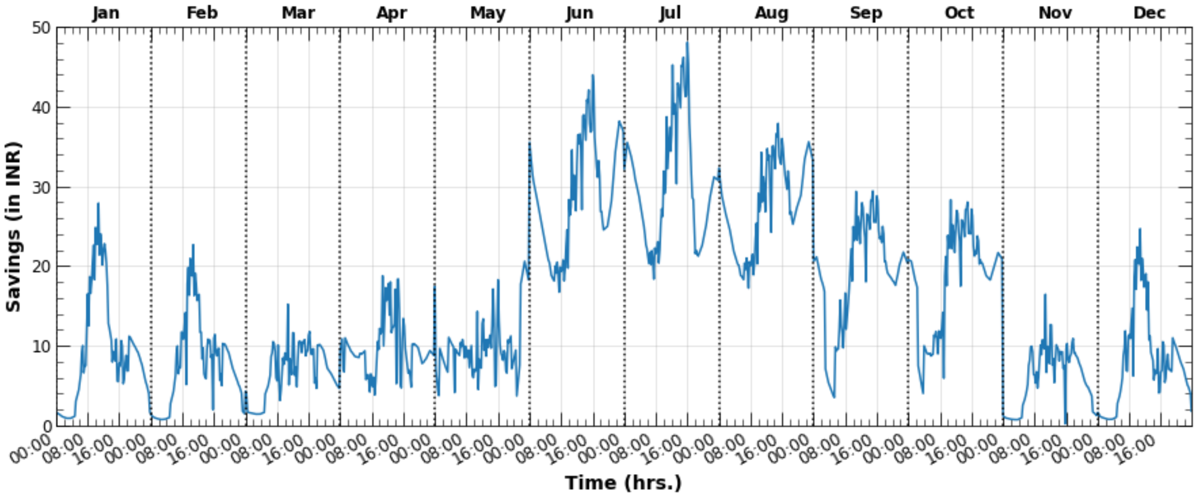


Figure 7:44: Savings made on reduction of losses for each time slot

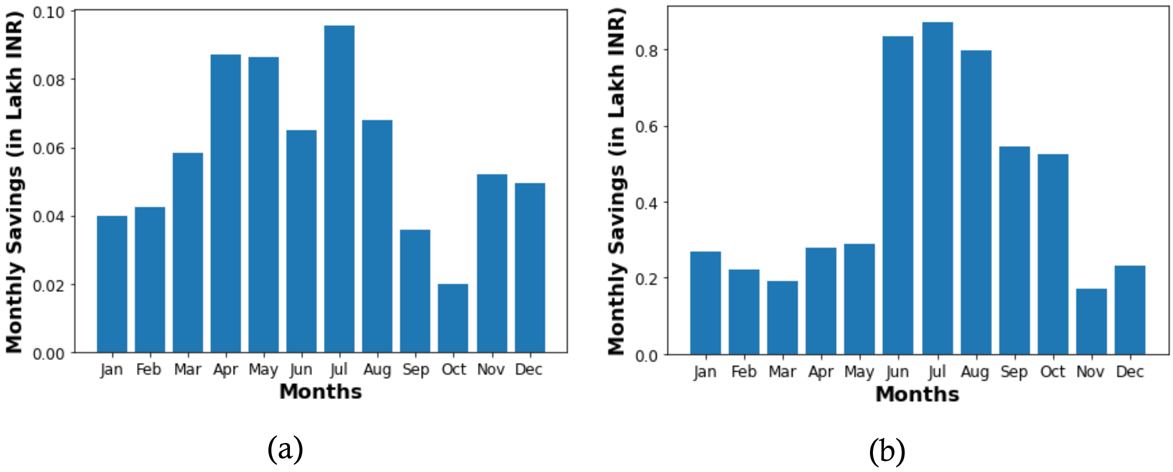


Figure 7:45: The monthly savings made by the DISCOM by reduction of losses in the network for (a) non-EV loads have a power factor of 0.95 and (b) non-EV loads have a power factor of 0.9

7.4.2 Captive PCS of bulk power/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. The food processing plant in Delhi is connected to the grid at the 11 kV terminal, as shown in Figure 7:46. The metering for the plant is done at the PCC point, so the captive charging station can be used to satisfy the local reactive power requirements of the plant.

The load curve of the plant is given in Figure 7:47, and the typical power factor of the industry is 0.63[82]. The resulting reactive power drawn from the grid is shown in Figure 7:48.

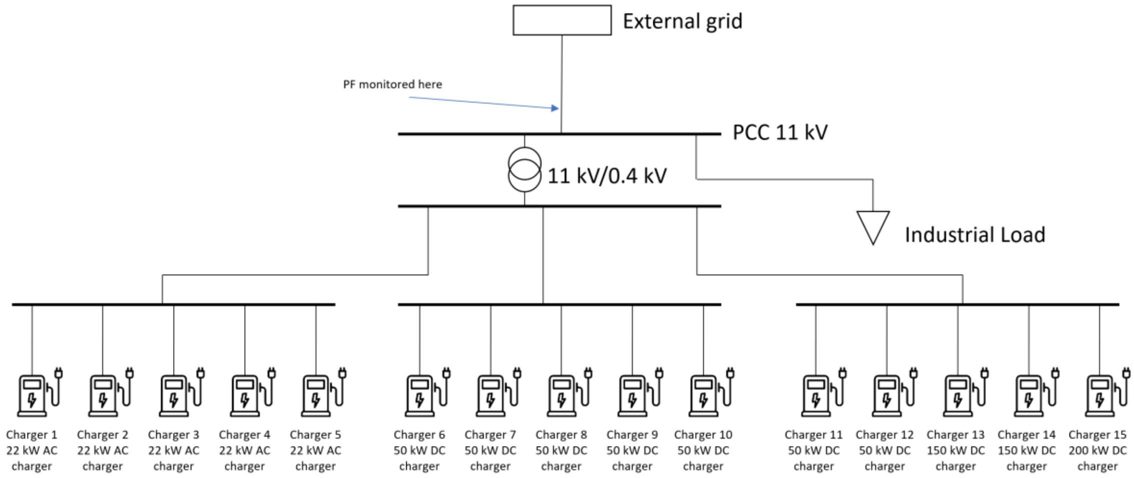


Figure 7:46: Schematic of industrial plant with captive EV charging station

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[82] BIS, IS 7752-1: Guide for improvement of power factor in consumer installation, Part 1

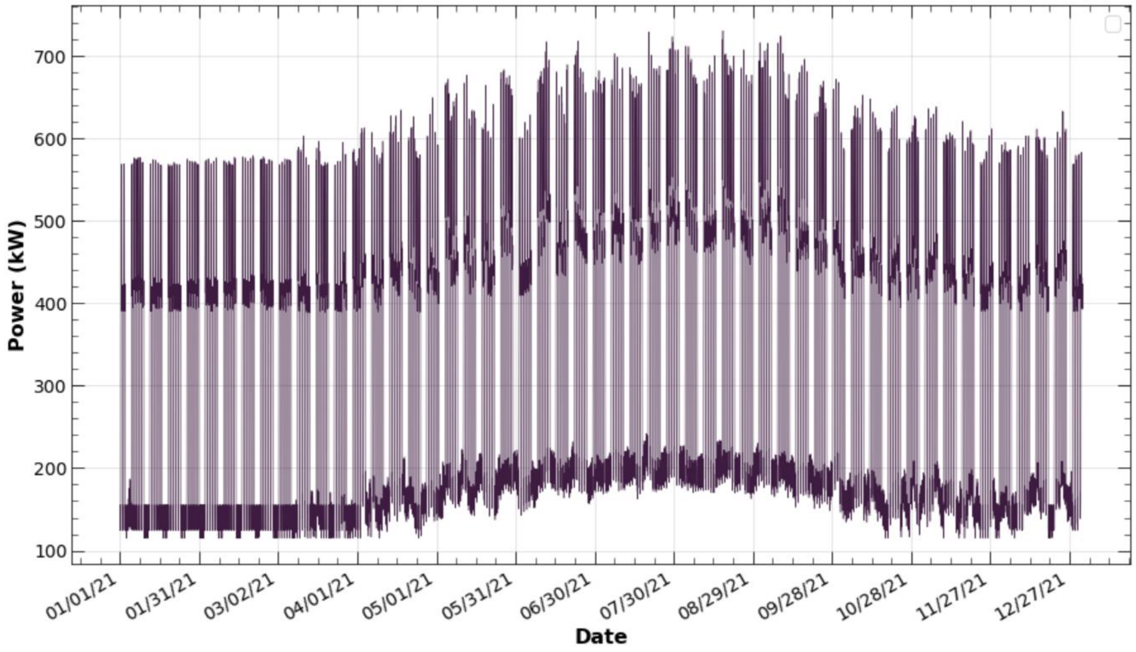

Figure 7:47: Load curve of food processing plant [83]

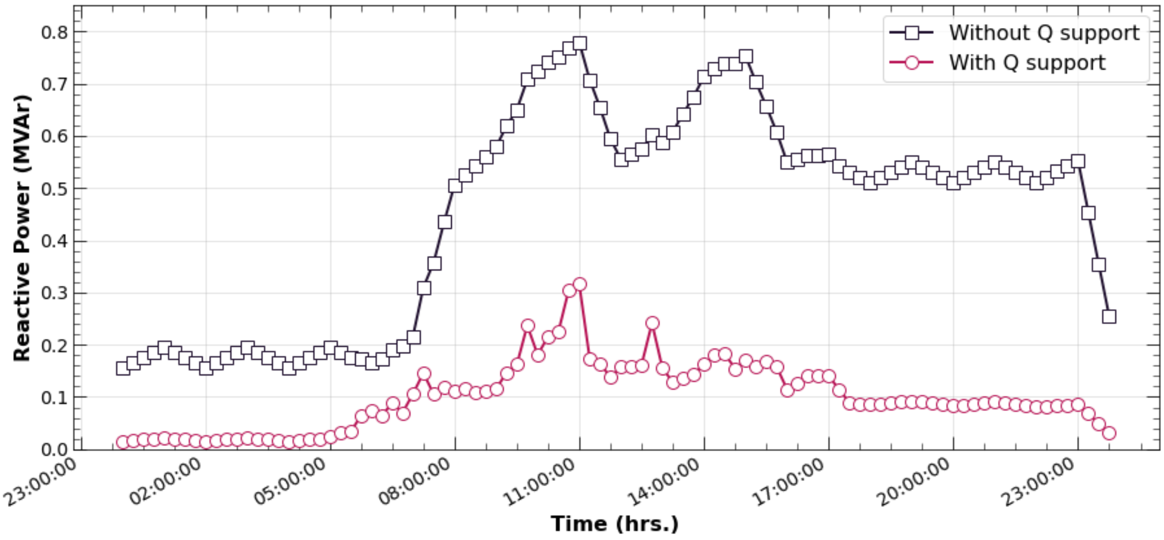

Figure 7:48: Reactive power drawn from the grid

The charging behaviour model described in Section 7.2.3 has been used to model the arrival of EVs to the charging station. Based on the arrival, the active power drawn by the charging station is shown in Figure 7:50(a). The voltage controller has been designed to

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[83] Farhad Angizeh, Ali Ghofrani, and Mohsen A. Jafari, "Dataset on Hourly Load Profiles for a Set of 24 Facilities from Industrial, Commercial, and Residential End-Use Sectors" 1 (August 21, 2020), https://doi.org/10.17632/rfnp2d3kjp.1.

achieve a power factor of at least 0.98 lagging at the PCC point of the industry. Depending on the existing power factor, the controller dispatches the required reactive power from the available margin in the charging station.

$$RP_{required} = P_{PCC} \times \tan\left(\phi_{actual} - \phi_{target}\right) \qquad \text{Eq. 5}$$

Where, $RP_{required}$ is the reactive power from the charging station, P_{PCC} is the active power drawn from the grid, ϕ_{actual} is the power factor at the PCC point without any corrective action and ϕ_{target} is the target power factor, which in this case is 0.98. The reactive power required is distributed among the EV chargers based on the availability margin. Figure 7:49 summarizes the impact of reactive power support from the charging station. As can be seen, without any support from the charging station, the power factor of the industry was 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. This phenomenon was reflected in the much-improved power factor at the PCC point. During morning and mid-day periods, the power factor at the PCC points appears to be improved even without any support from the EV charging station. However, this is only because, during this period, the charging station drew high active power (at unity power factor), resulting in an improved power factor at the PCC even though the plant was still consuming high reactive power.

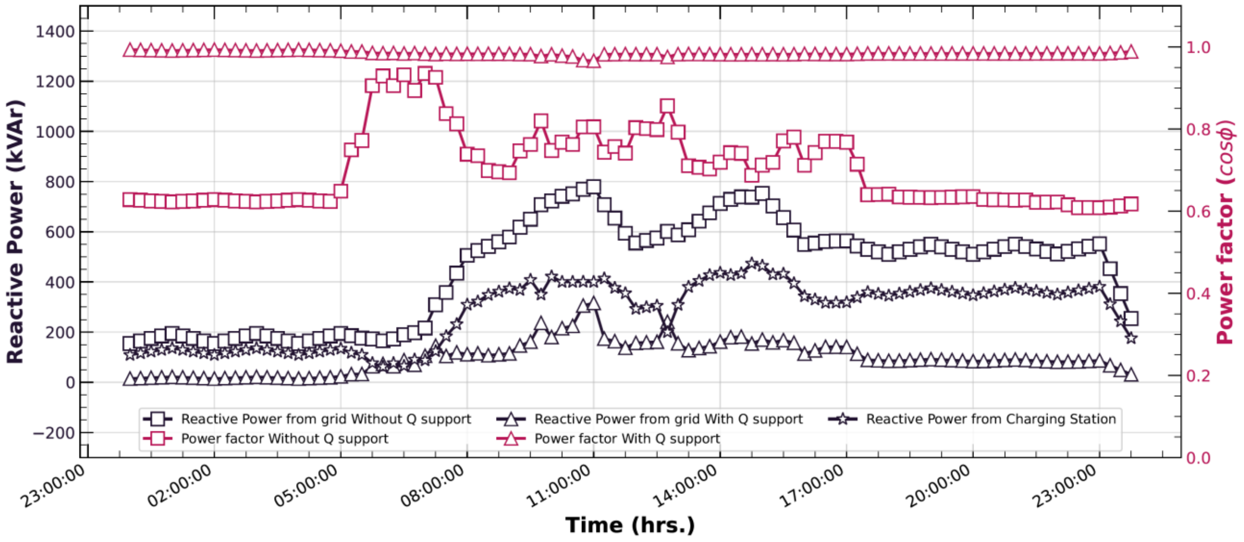
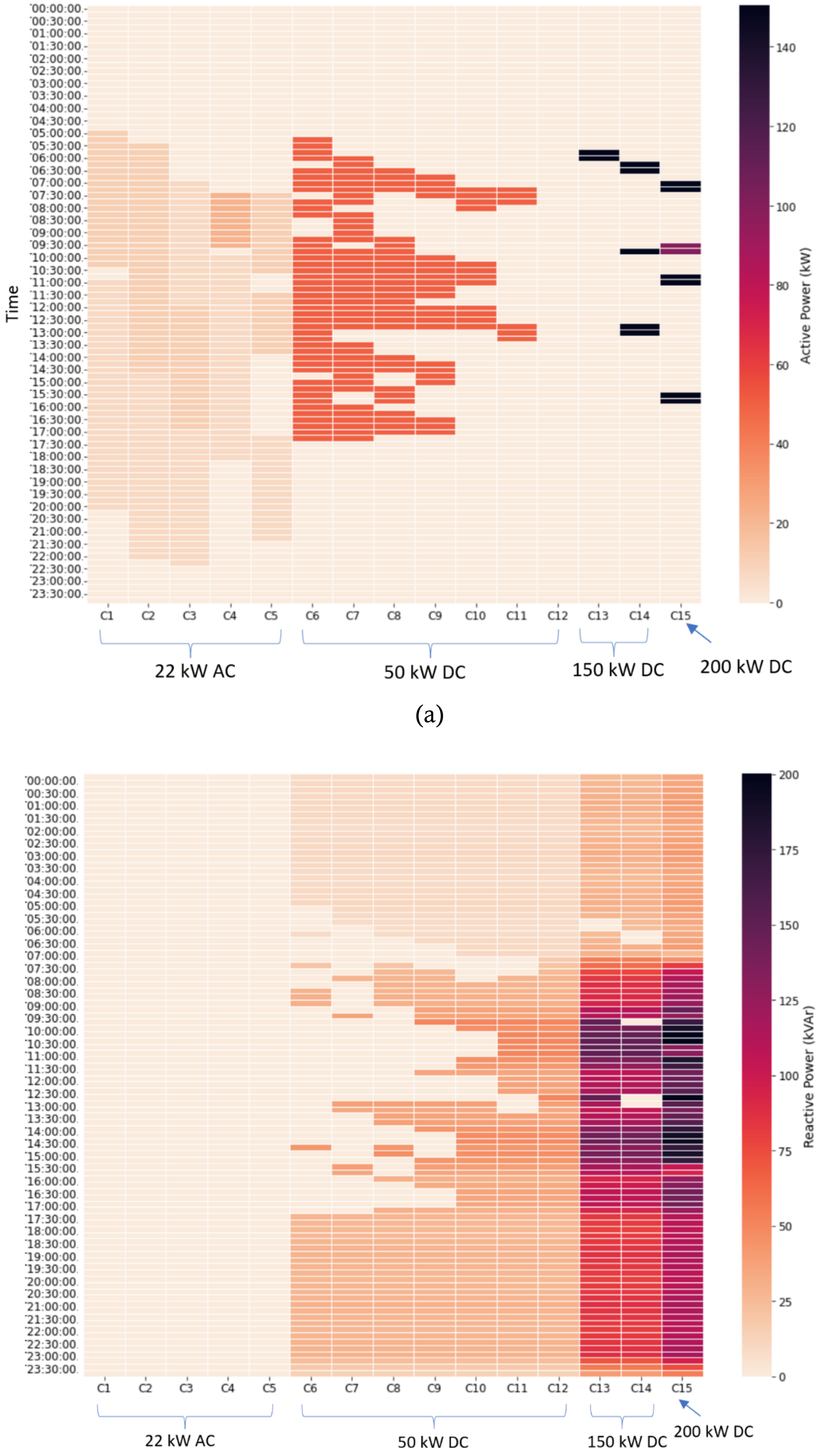


Figure 7:49: Reactive Power and Power factor of the industry with and without support from the charging station

The reactive power provided by the charging station has been shared among the different chargers, with the major share provided by the high-capacity DC chargers. From Figure 7:50, the 150-kW and 200-kW DC chargers are utilized for EV charging only for a few hours of the day, making these chargers an attractive source of reactive power. The 50-kW DC chargers can also be utilized to provide reactive power, but not during periods when it is charging a vehicle, as shown in Figure 7:50.

The provision of reactive power from the EV charging station has also affected the voltage at the PCC point of the industry. Figure 7:51 indicates that the reactive power support has also helped improve the voltage profile. Specifically, during the evening peak period, the support from the charging station helped raise the voltage from 0.968 p.u. to higher than 0.99 p.u.



(a)

(b)

Figure 7:50: (a) Active and (b) Reactive Power from individual chargers in the charging station throughout the day

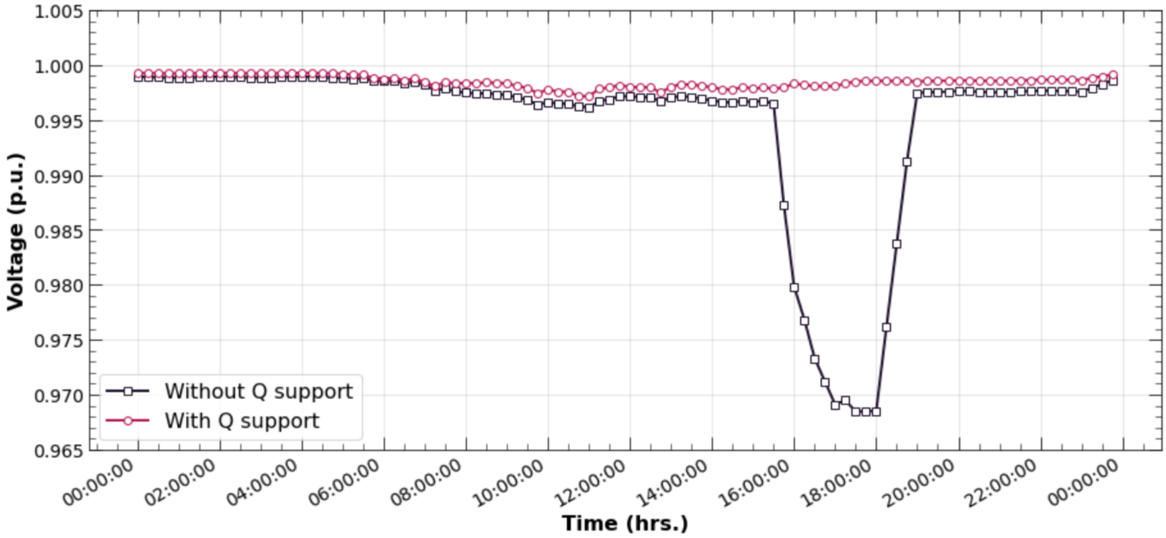


Figure 7:51: Impact of reactive support from EV charging station on voltage profile at the PCC point

7.4.2.1 Cost benefit analysis

For analysing the financial impact of reactive power from EV charging stations, the Delhi electricity tariff for 2021-2022 has been considered. As per the regulations of the Delhi Electricity Regulatory Commission, industrial units are charged based on a two-part tariff, as shown in Table 7.3.

Table 7.3: Delhi industrial tariff (Source: DERC)

Demand Charge (INR/kVA/Month)	Energy Charge (INR/kVAh)
250	7.75

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. The incorporation of reactive power support from the charging station has decreased the apparent power drawn from the grid, as shown in Figure 7:52. This results in a reduction of both the demand charge and the energy charge of the industry. By utilizing the reactive power support from the charging station, the industry can reduce its monthly demand charges from INR 3,28,687 (EUR 3,882) to INR 3,07,596 (EUR 3,633), i.e. a savings of INR 21,090 (EUR 250) per month or INR 2,53,087 (EUR 2,990) per year. Looking at the energy savings, the charging station can reduce the daily energy bill from INR 1,24,725 (EUR 1,473) to INR 1,01,789 (EUR 1,202), i.e. a saving of INR 22,936 (EUR 271) per day or INR 71,79,234 (EUR 84,810) per year can be made, as highlighted in Table 7.4.

Table 7.4: Financial analysis

	Demand Charge (INR/kVA-Month)	Energy Charge (INR/kVAh-day)
Without Q support	INR 3,28,687	INR 1,24,725
With Q Support	INR 3,07,596	INR 1,01,789
Savings	INR 21,090 (per month)	INR 22,936 (per day)
Annual Savings	INR 2,53,087	INR 71,79,234

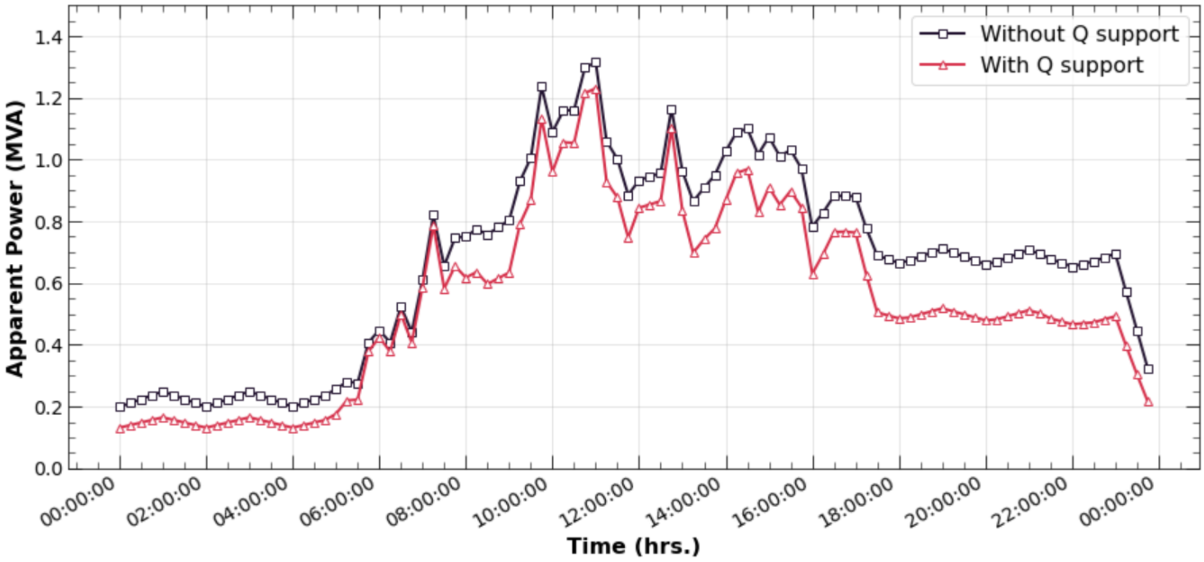


Figure 7:52: Apparent power consumed by the industry with and without support from the EV charging station

7.5 Conclusion

From the analysis, it can be observed that reactive power support from EVs can provide significant benefits to the DISCOMs as well as large industrial/commercial entities. As the DC EV chargers are likely to be distributed along the distribution feeders, so enabling reactive power support from these distributed chargers can lead to significant improvement in the voltage profile of the feeders along with decreasing the losses in the network. Enabling such support from EVs would require the EV chargers to have four quadrant operation so that they can absorb from or inject reactive power to grid, irrespective of whether the charger is charging, discharging or idle.

Chapter 8. Frequency Support from Electric Vehicles

8.1 Introduction

The controllable and fast-acting nature of EVs also makes them well-suited for providing frequency support services. In this section, the capability, and the economic impact of EVs providing frequency regulation services have been analyzed.

8.2 Test System Modelling

In this case study, the potential benefits of provisioning frequency regulations services from EVs have been explored. The different aspects of modelling the case study have been described in this section.

8.2.1 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.

As per the latest Draft Indian Grid Code 2022, the frequency should nominally lie in a narrow band between 49.95 Hz and 50.05 Hz[84].

8.2.2 Frequency Characteristics

Real frequency data shown in Figure 8:1 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. In Figure 8:1, multiple dips below 49.9 Hz and spikes above 50.1 Hz can be seen. 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,

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[84] CERC, "Draft Indian Electricity Grid Code Regulations 2022," July 7, 2022.

the frequency was above 50.1 Hz as shown in Figure 8:2. This characteristic needs to be accounted for during the modelling of the frequency regulation controller.

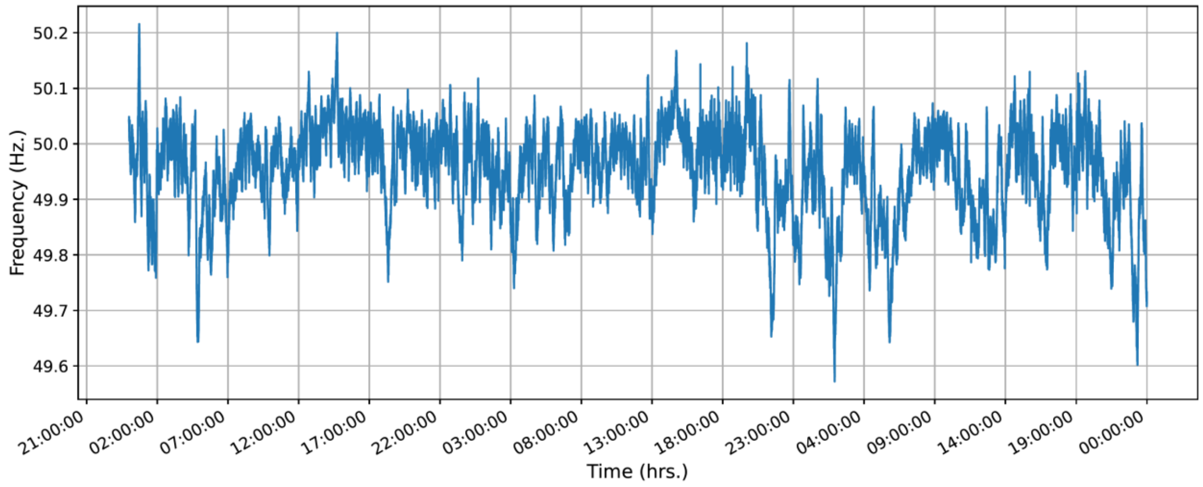

Figure 8:1: Frequency data

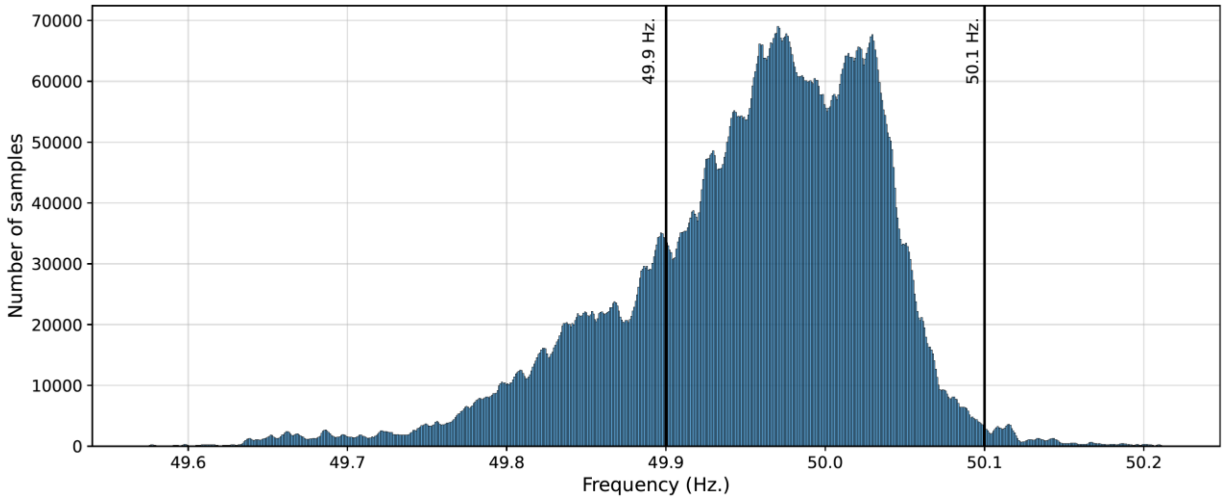

Figure 8:2: Histogram plot of the frequency measurement data

8.2.3 EV behaviour Modelling

An Indian urban commute distance database was used to model the distance travelled by the EVs. Presented in Figure 8.3, the survey identified that most one-way urban commutes (using cars) in India are less than 40 km, with a mean travel distance of around 10 km.

Considering that the driving pattern of people will be fuel agnostic, the behaviour model used has been modelled as per the driving characteristics of gasoline vehicles [85]. The load profile due to the addition of EVs is dependent on the EV penetration, distance travelled by each EV, the probability of charging of each EV and the charging power drawn. In addition to this, the arrival and departure time is also needed. The charging probability of each EV is dependent on the state-of-charge (SoC) of the EV battery.

The SOC is defined as the percentage of remaining battery capacity and can be expressed using Eq. 6.

$$SoC = \frac{E_d}{E_n} \qquad \text{Eq. 6}$$

where, E_d is the remaining energy in the battery and E_n is the rated capacity. When the SOC falls below a certain threshold, the EV is charged. So, at the end of each day, the SOC of each EV is computed using Eq. 7.

$$SoC(d) = SoC(d-1) - x(d) \times C \qquad \text{Eq. 7}$$

where, $x(d)$ is the distance travelled on day d, and C is the energy consumption per distance travelled.

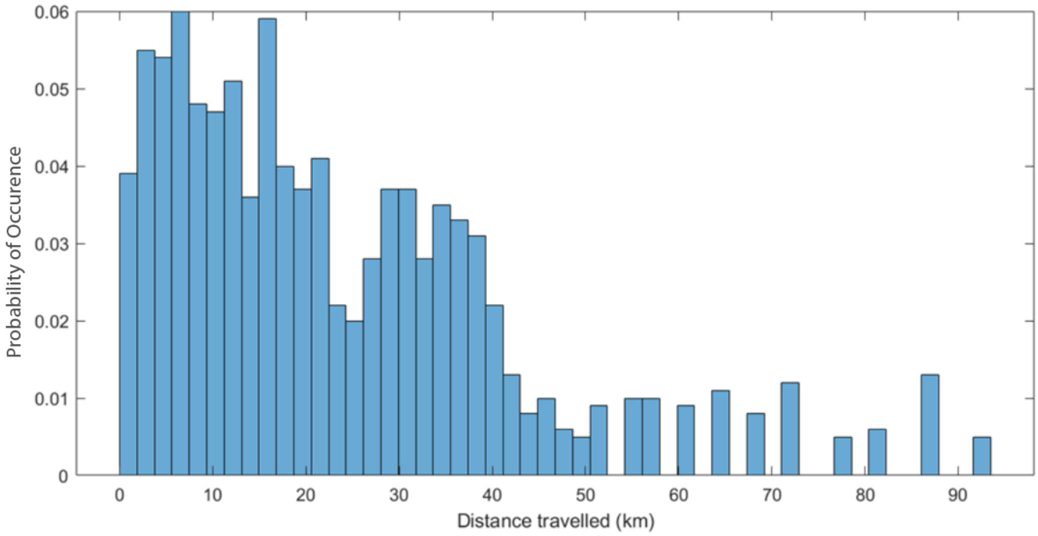

Figure 8:3: Length of one-way urban commute in India [86]

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[85] Lisa Calearo et al., "Grid Loading Due to EV Charging Profiles Based on Pseudo-Real Driving Pattern and User Behavior," *IEEE Transactions on Transportation Electrification* 5, no. 3 (September 2019): 683–94, https://doi.org/10.1109/TTE.2019.2921854.

[86] Abhinav Soman, Harsimran Kaur, and Karthik Ganesan, "How Urban India Moves: Sustainable Mobility and Citizen Preferences," October 2019, https://www.ceew.in/sites/default/files/CEEW-How-Urban-India-Moves-Report-PDF-22Oct19-compressed.pdf.

After determining whether an EV will be charged in the day, it is necessary to determine the time duration for which the EV will be charging. This is dependent on the SOC at the time when the EV was plugged in and the charging power which can be defined as Eq. 8.

$$T_c = \frac{\left(\left(SoC_{req} - SoC(d)\right) \times E_n\right)}{P_c \times \eta_c} \qquad \text{Eq. 8}$$

where, T_c is the time required for charging, SoC_{req} is the minimum SOC, the vehicle owner wants to have before the next trip, P_c is the charging power and η_c is the charging efficiency. The temporal distribution of EV charging demand also depends on when the EV will be plugged in. A statistical distribution of EV arrival/departure time has been shown in

Figure 8:4. It has been considered that the EVs can charge either at home or in public charging stations or both, and they are plugged in immediately on reaching their preferred charging destination, which has been discussed earlier. An EV once plugged in, would remain so until the time the EV is on the road again. But, based on the time required for charging, which has been determined using Eq. 8, and the duration for which the vehicle is plugged-in, the vehicle may not draw any power from the grid for some period even if it is plugged in.

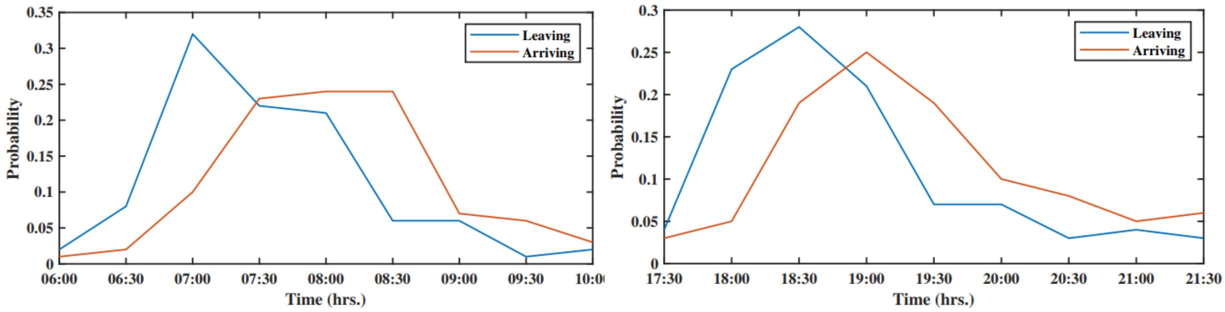

Figure 8:4: Probability of vehicle leaving home and arriving at destination in the morning (left), and leaving destination and arriving home in the evening (right) [87]

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[87] Xinyu Chen et al., "Impacts of Fleet Types and Charging Modes for Electric Vehicles on Emissions under Different Penetrations of Wind Power," Nature Energy 3, no. May 2018 (2018), https://doi.org/10.1038/s41560-018-0133-0.

8.2.4 Frequency Response Modelling

During the provision of frequency regulation, the response from the EV has been modelled, as shown in Eq. 9.

$$P_{FR} = \begin{cases} -\alpha P_{rated} + offset, \ if \ f < 49.9\ Hz \\ -\dfrac{50-f}{0.1}\alpha P_{rated} + offset, \ if \ 49.9 \le f \le 50.1 \\ \alpha P_{rated} + offset, \ if \ f > 50.1\ Hz \end{cases} \qquad \text{Eq. 9}$$

here, P_{FR} is the response of an EV, α is the participating factor, P_{rated} is the rated charging power of the EV, f is the frequency of the grid. As shown in Figure 8:2, the frequency in the Indian grid often lies lower than the nominal frequency band, so the factor $offset$ has been introduced, so that the EV is not continuously discharged and is defined as given in Eq. 10. The resulting response curve has been shown in Figure 8:5.

$$offset = \frac{\alpha P_{rated}}{0.1} \times (f_{mean} - 50) \qquad \text{Eq. 10}$$

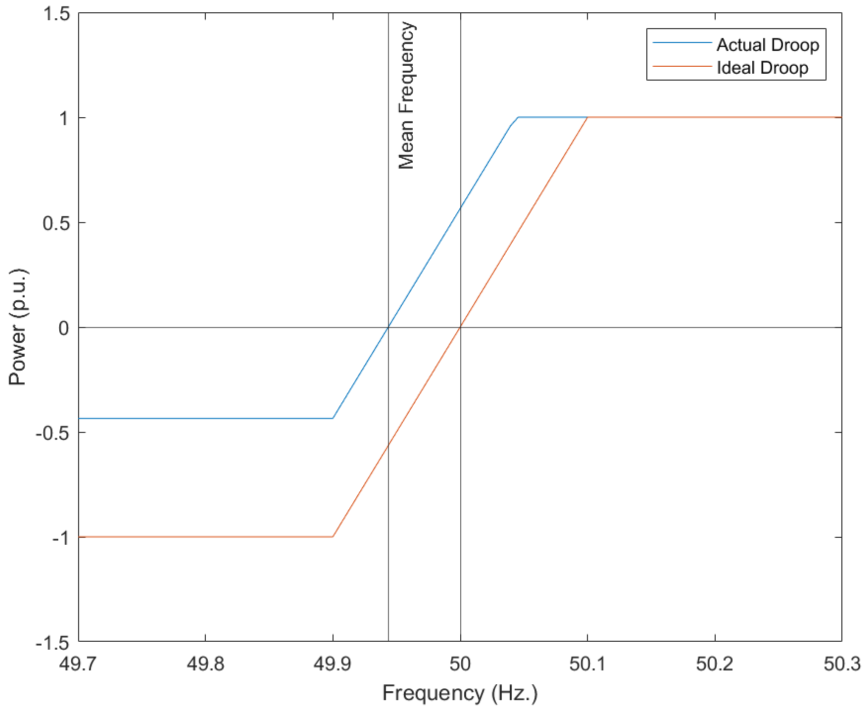

Figure 8:5: Frequency response characteristic

8.2.5 Revenue assessment

Frequency regulation is paid based on the availability of the resource. So, the revenue that the EV user can earn is based on the power capacity that is being made available per time slot and not on the actual energy that is provided during response. However, a minimum bid amount is often mandated by grid operators. If the aggregated capacity of the resource is less than the minimum bid amount, the resource is not allowed to provide frequency regulation service. Thus, revenue earned is calculated using Eq. 11,

$$Rev_{FR} = \sum_{0}^{t_{FR}} \left(\sum^{n_{EV}} \alpha P_{rated} \times C_{FR}(t) \right), \qquad \forall \sum^{n_{EV}} \alpha P_{rated} > P_{minbid}^{FR} \qquad \text{Eq. 11}$$

where, Rev_{FR} is the daily revenue earned by the fleet aggregator, t_{FR} is the number of hours of service provided, n_{EV} is the number of EVs in the fleet, $C_{FR}(t)$ is the payment for the regulation service and P_{minbid}^{FR} is the minimum bid amount required for the provision of frequency regulation service.

8.3 Techno-Economic Analysis

For this case study, it has been considered that the EV aggregator has 1000 vehicles registered under it willing to provide the necessary regulation. The study is conducted for a simulation period of 30 days, where each EV has a random travel distance based on the travel probability shown in Figure 8.3

The details of the EV considered are provided in Table 8.1.

Table 8.1: Details of EV considered in this analysis

Electrical Vehicle Parameters	Value
Size of EV Battery (kWh)	40
Charger Rating (kW)	22
Minimum SoC	0.2
Maximum SoC	0.9
Charger Efficiency (%)	90
EV consumption (kWh/km)	0.15
Time step (Δt) (in min)	15

A representative sample showing the distance travelled by the EVs is shown in Figure 8:6. Based on the distance travelled and the current SoC of the EV battery, the EV user charges their EV. It has been considered that the user plugs in their EV if its SoC drops below 0.6[88]. Based on this condition, the number of charging sessions started by an EV user is given in Figure 8:7, which shows that, on average, an EV user charges their vehicle 7 times in 30 days, i.e., approximately every 4 days. Here, it has been considered that an EV is plugged into the grid only if the EV user needs to charge their vehicle[89].

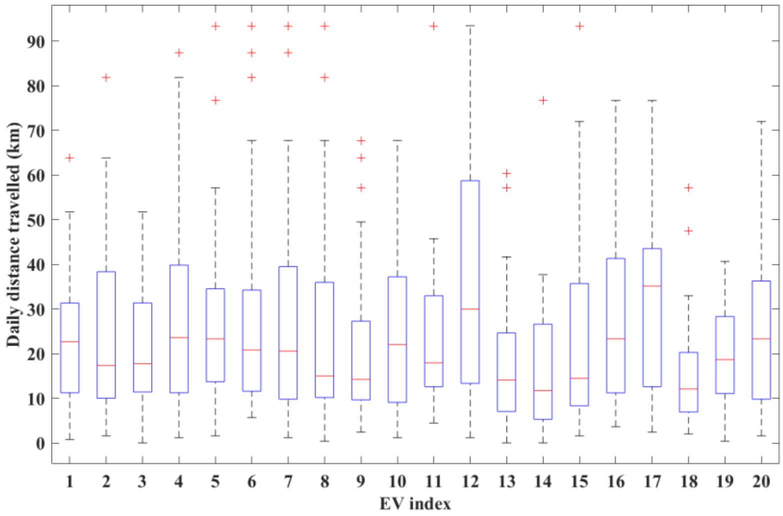

Figure 8:6: Distance travelled by each EV over the course of 30 days (shown for 20 EVs)

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[88] Calearo, Lisa, Andreas Thingvad, Kenta Suzuki, and Mattia Marinelli. "Grid loading due to EV charging profiles based on pseudo-real driving pattern and user behavior." IEEE Transactions on Transportation Electrification 5, no. 3 (2019): 683-694.

[89] 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.

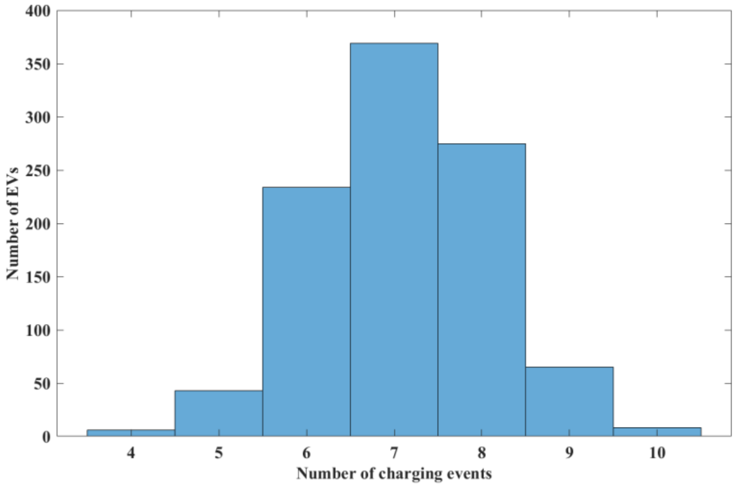

Figure 8:7: Histogram showing the number of charging events in 30 days

The number of EVs plugged in to the grid during the day is shown in Figure 8:8, where each line represents a different day. As can be seen, most EVs start plugging in during the evening from around 6 PM. By midnight most EVs that have charging requirements are plugged-in. In the afternoon, a small percentage of EVs are plugged-in, which represents office charging. Comparing Figure 8:8 with Figure 8:9, it can be seen that although EVs are plugged-in, it does not necessarily imply that EVs are charging. The charging load is mainly clustered from 6 PM to 11 PM (residential charging) and between 7 AM to 11 AM (workplace charging). For the rest of the period, the EVs are plugged-in but remain idle. This provides the opportunity for the utilization of EVs in providing the regulation service.

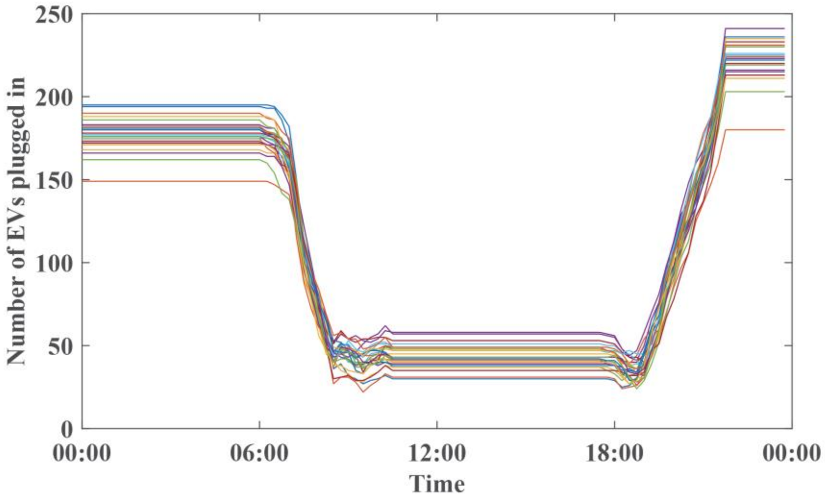

Figure 8:8: Number of EVs plugged-in to the grid

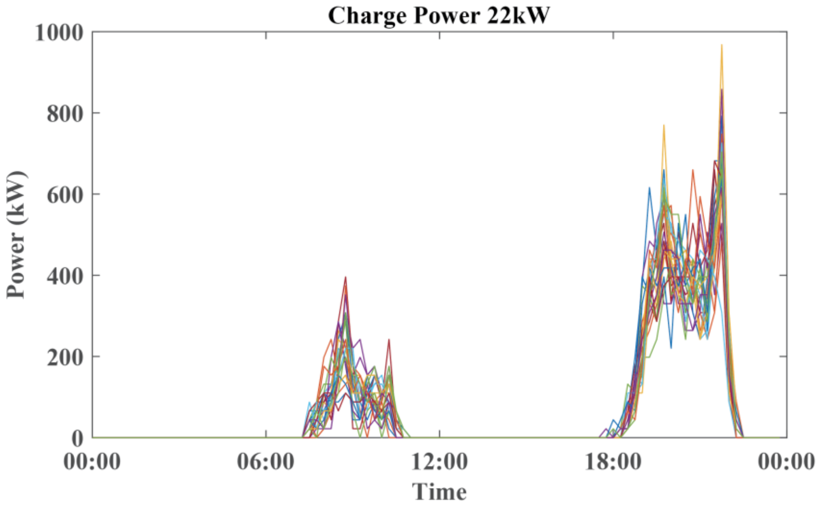

Figure 8:9: Cumulative EV charging load

For the execution of regulation service, the aggregator measures the local frequency and commands the EVs to respond to the frequency based on Eq. 9. 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. This period has been chosen because, during this time, EVs are plugged-in but remain idle, and, the price of the regulation signal is highest, as shown in Figure 8:12. Three different participation factors have been considered in this study, 0.4, 0.7 and 1. 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.

The participation factor significantly impacts the provision of the regulation service. As can be seen in Figure 8:10, with a lower participation factor, the reserve available with the EV aggregator is less. With a participation factor of 0.4, the EV aggregator can participate in the frequency regulation service up to 7:30 AM, as beyond this, the total reserve available goes below 1000 kW. However, with a higher participation factor, the aggregator can provide the service for a longer duration.

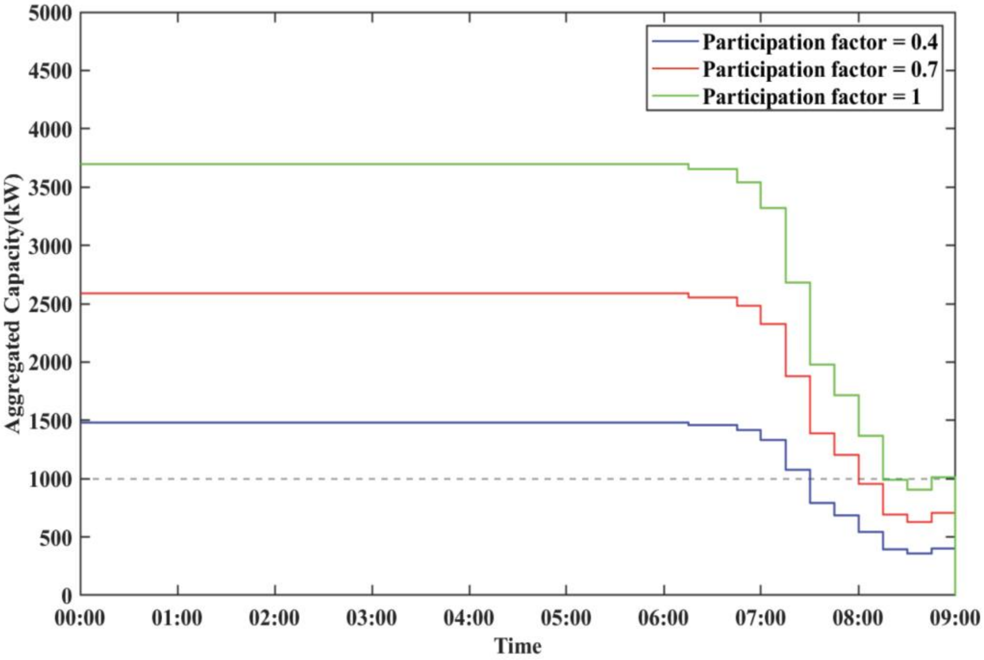

Figure 8:10: Total quantum of regulation reserve available with the aggregator for different time slots (for 1 day)

The EV aggregator response is shown in Figure 8:11, which shows the EV aggregator responding to the deviation of the frequency signal from the mean frequency. If the frequency is higher than the mean frequency, the EVs participating increase their charging power to reduce the deviation. In comparison, if the frequency is lower than the mean frequency, the EVs discharge their batteries. The response is proportional to the frequency deviation as well as the participating factor.

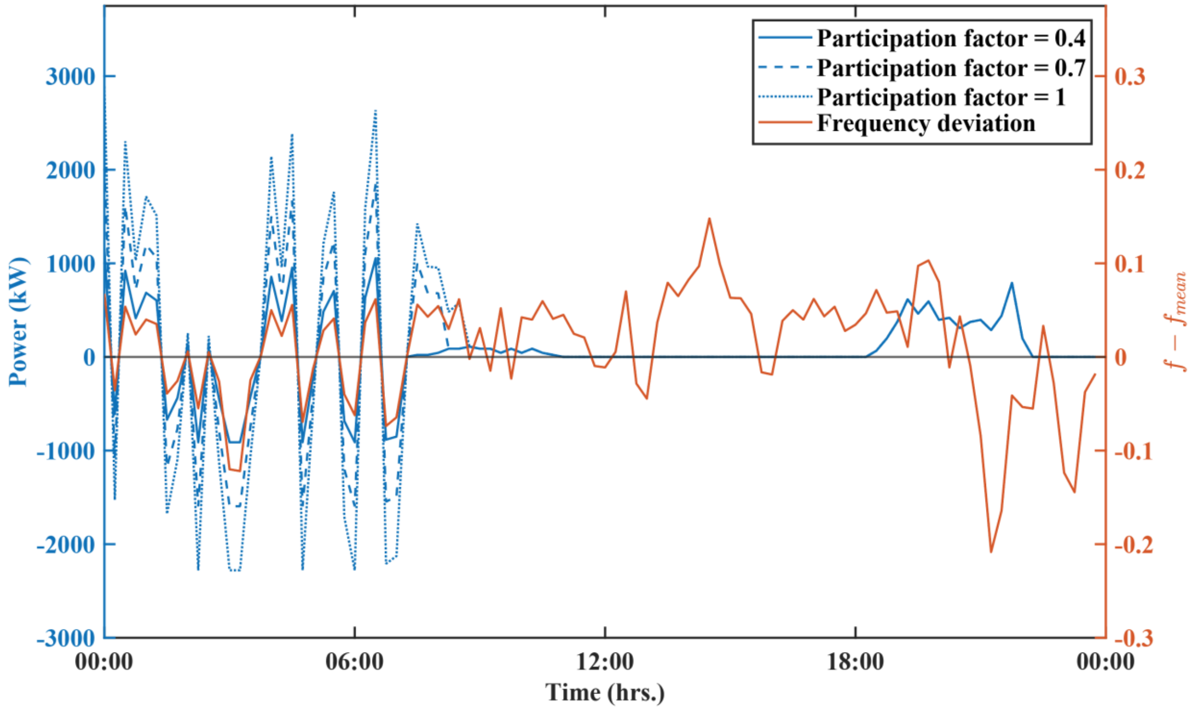

Figure 8:11: Frequency regulation service provided by the EV aggregator (shown for 1 day)

The cost of regulation service based on resource availability is shown in Figure 8:12. Considering this cost and the availability of resources, the annual aggregator revenue is shown in Figure 8:13. As expected, with a higher participation factor, the revenue earned by the aggregator increases, from INR 90 lakh when the participation factor is 0.4 to INR 2.35 crore when the participation factor is 1. This revenue is then shared among the EV users based on the contribution of each user, as shown in Figure 8:14.

From Figure 8:14, EV users can earn a considerable 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. 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 8:15 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 revenue earned by the EV user from participating in regulation services increases [90].

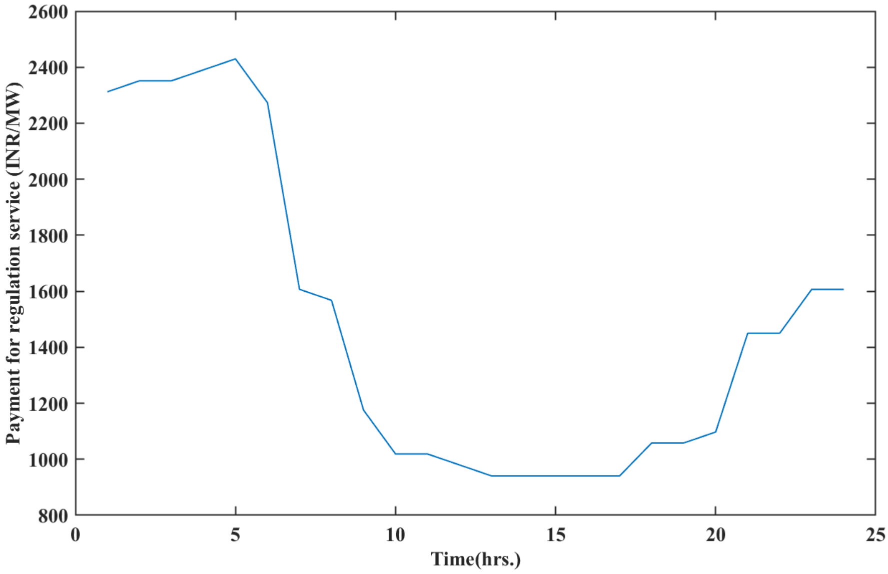

Figure 8:12: Cost of regulation service [91,92]

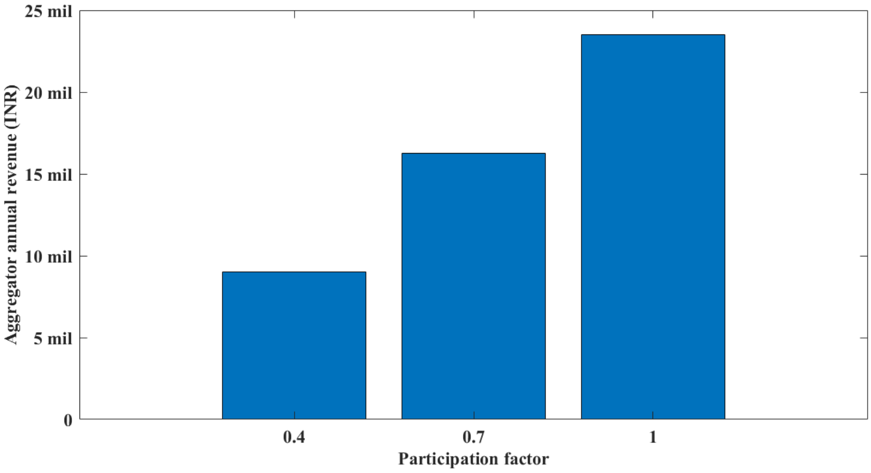

Figure 8:13: Aggregator annual revenue by the provision of frequency regulation service

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[90] 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.

[91] The price has been taken from the Danish frequency regulation price of 2018. The price is then scaled based on the ratio of the Danish electricity price and the Indian electricity price.

[92] Lisa Calearo and Mattia Marinelli, "Profitability of Frequency Regulation by Electric Vehicles in Denmark and Japan Considering Battery Degradation Costs," *World Electric Vehicle Journal, MDPI*, July 16, 2020.

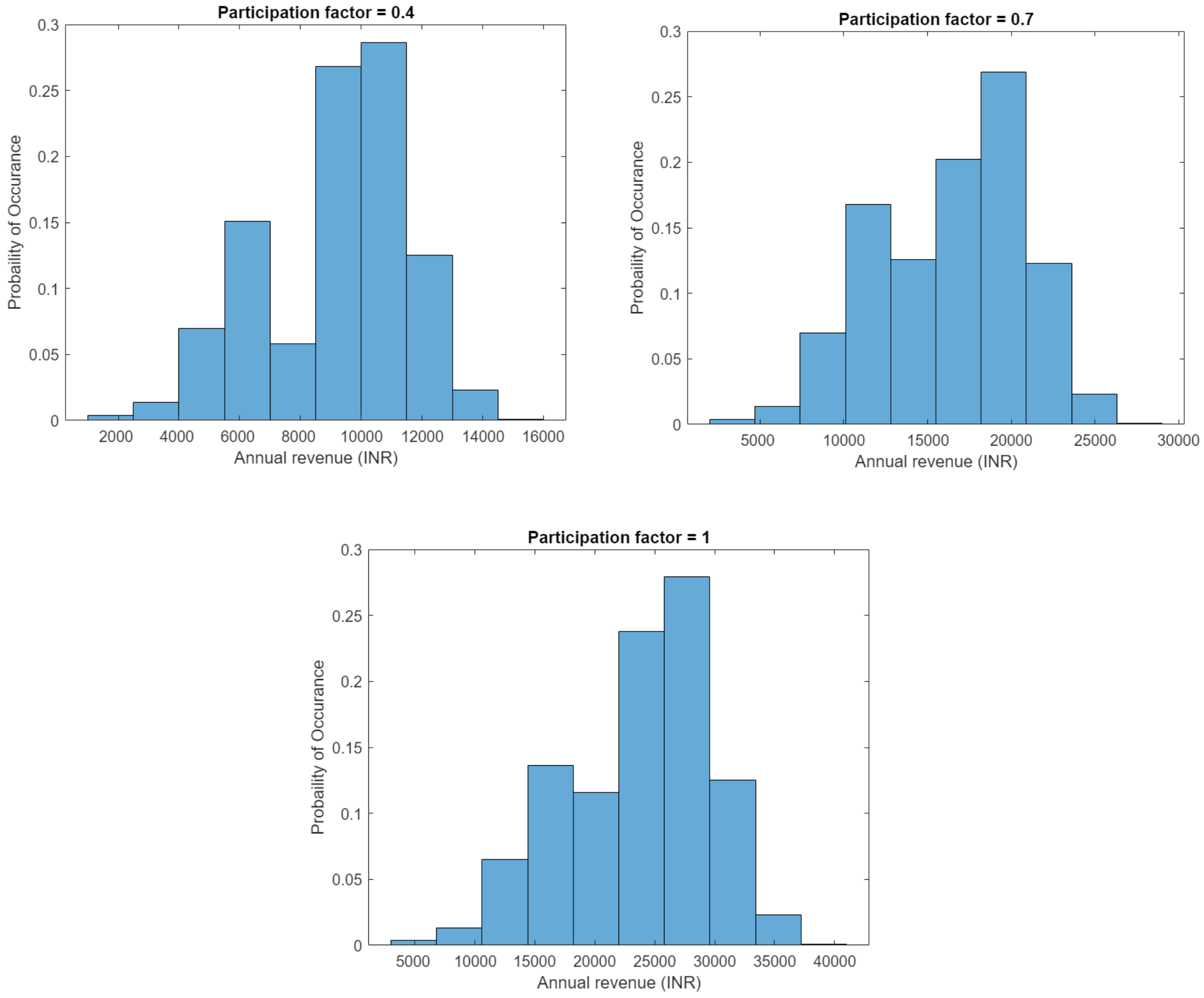

Figure 8:14: Histogram showing the annual revenue earned by EV users for different participation factors

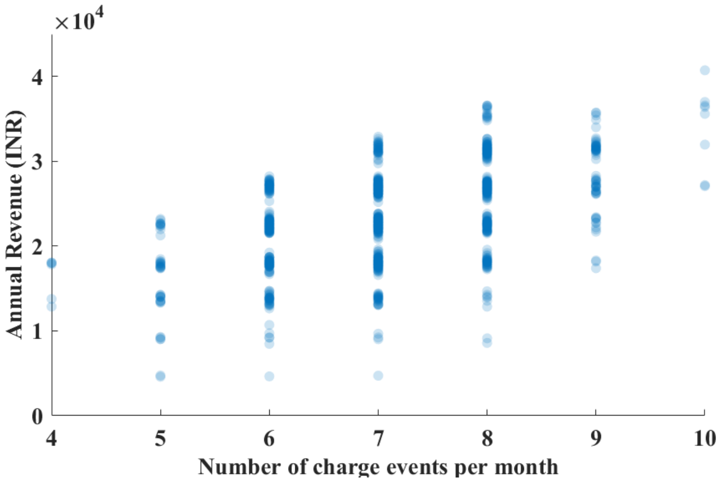

Figure 8:15: Annual revenue earned by the provision of frequency regulation service vs the number of charging events undertaken by the EV user in a month (shown for participation factor of 1)

However, with a higher participating factor, the impact of providing regulating service on the EV would also be higher, and there is higher volatility in the SoC level as the EV is charged/discharged with a higher power capacity compared to a low participation factor, as shown in Figure 8:16. So, here 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. So, depending on the travel requirements of the EV user, they can opt for a higher participating factor or vice-versa.

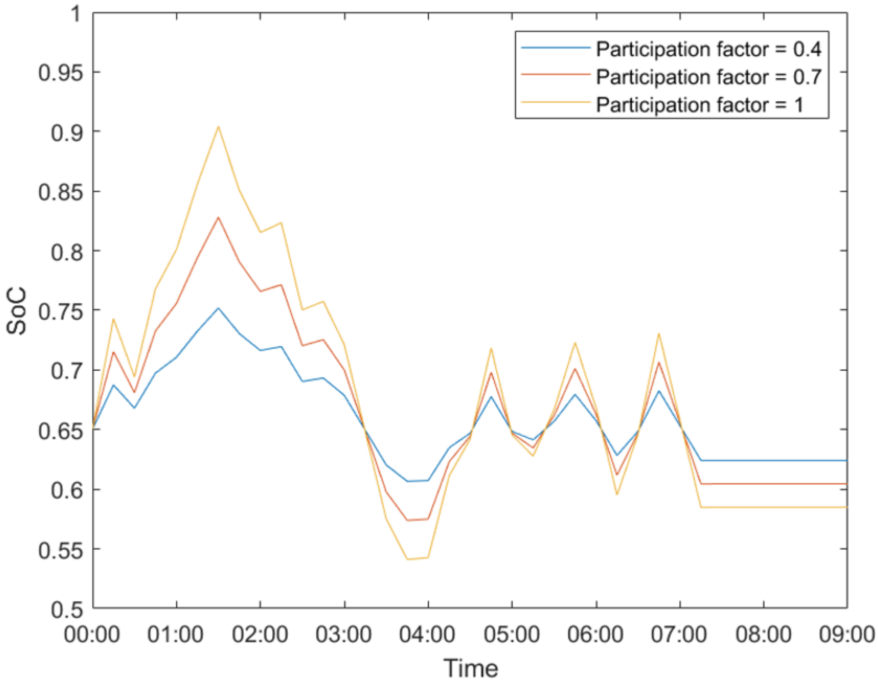

Figure 8:16: State of Charge of EV due to the provision of regulation service

8.3.1 Sensitivity and dimensional analysis

The revenue from the provision of frequency regulation services is sensitive to different factors explored in this section.

Figure 8:17 highlights the sensitivity of annual revenue earned by EV users to its rated charging power, which shows that with increasing charging power, the potential revenue earned by EV users tends to increase.

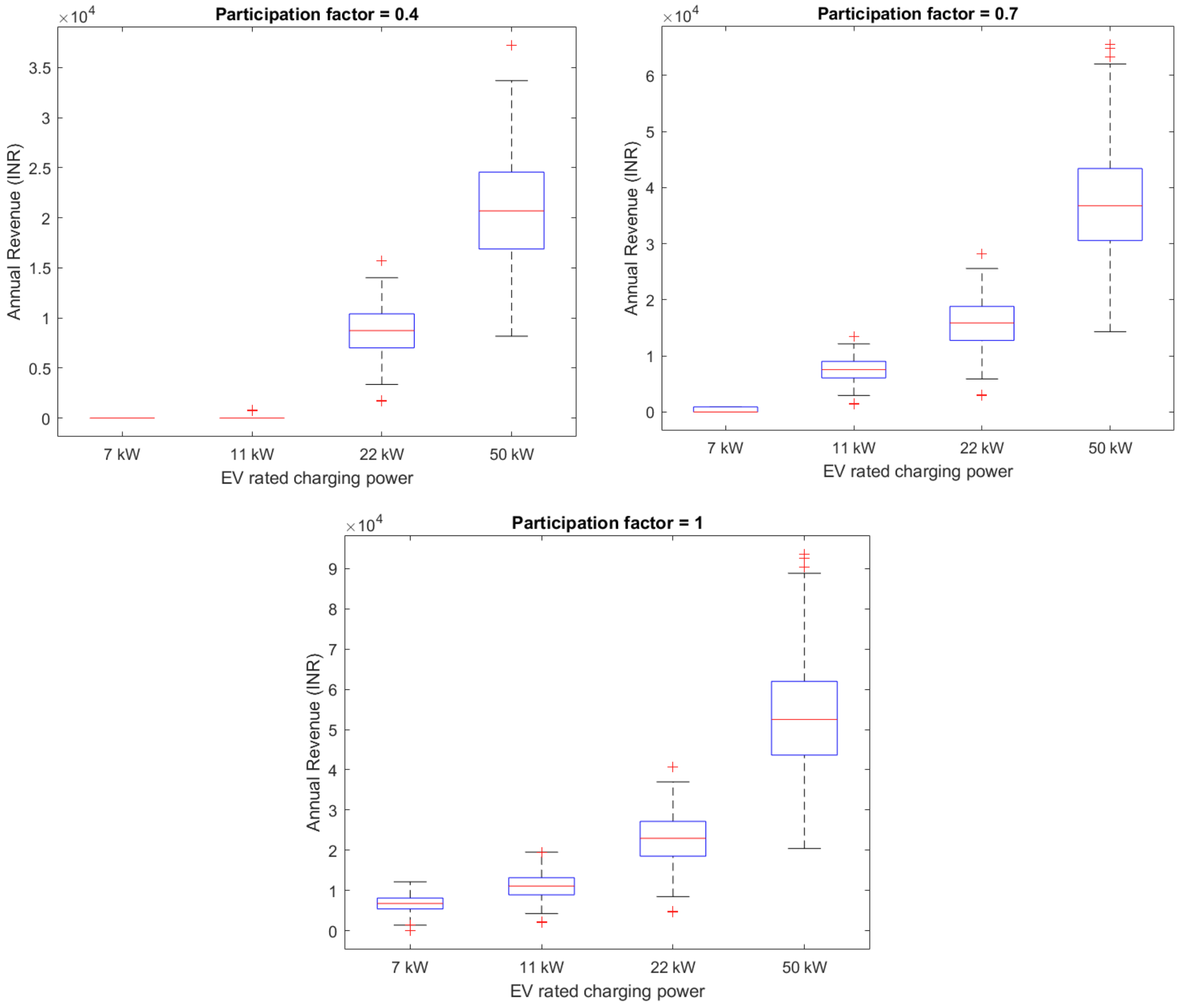

Figure 8:17: Sensitivity of annual revenue to the rated power of EV charging

For 7-kW and 11-kW charging, no revenue was earned by the EV users for a participation factor of 0.4 and marginal revenue for a participation factor of 0.7. This can be attributed to the fact that for lower charger power capacities, the cumulative reserve availability does not exceed the minimum bid capacity of 1000 kW, as shown in Figure 8:18, thereby preventing the EV users from participating in the service. Further, the revenue earned is also correlated to the amount of reserve available. Figure 8:18 highlights that with a higher charging capacity, the reserve margin available to the aggregator is higher, which implies that he can bid higher reserves to the regulation market, thereby increasing the revenue. At low charging capacities, the EV aggregator may not have energy reserve available to participate in the regulation service highlighted in Figure 8:18. To increase the reserve margin, the aggregator can,

a) Increase the charging capability of the EVs (difficult to implement in a short period)
b) Increase the number of vehicles in its fleet.

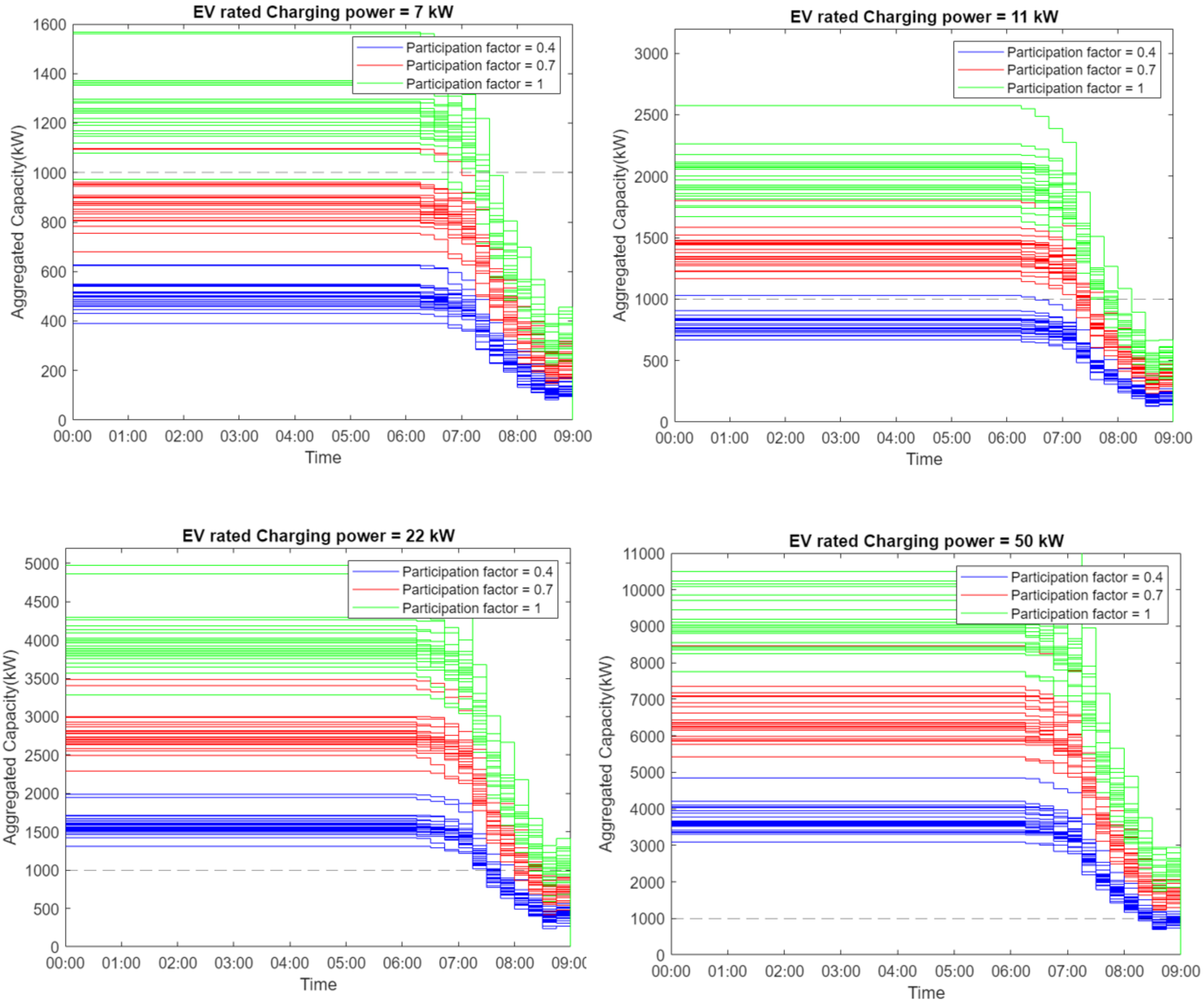

Figure 8:18: Aggregated capacity available to the EV aggregator

The sensitivity of the aggregator revenue to the number of EVs in its fleet has been shown in Figure 8.19 which shows that as the number of EVs under the aggregator increases, there is an increase in the earned revenue. In the case of charging power of 7 kW, by doubling the number of EVs, the aggregator was able to earn revenue even at a 0.4 participating factor. If the aggregator is already earning revenue, there is a linear relationship between the number of EVs under the aggregator and the total revenue earned.

However, the same cannot be said of the revenue made by individual EV users. Figure 8:20 shows the sensitivity of the revenue earned by individual EV users to the number of EVs under the aggregator, from which it can be seen that increasing the number of EVs under the aggregator can increase the revenue earned by each user, provided that the addition of users enabled the aggregator to participate in the regulation service, that happens when the EV charging power is 7 kW.

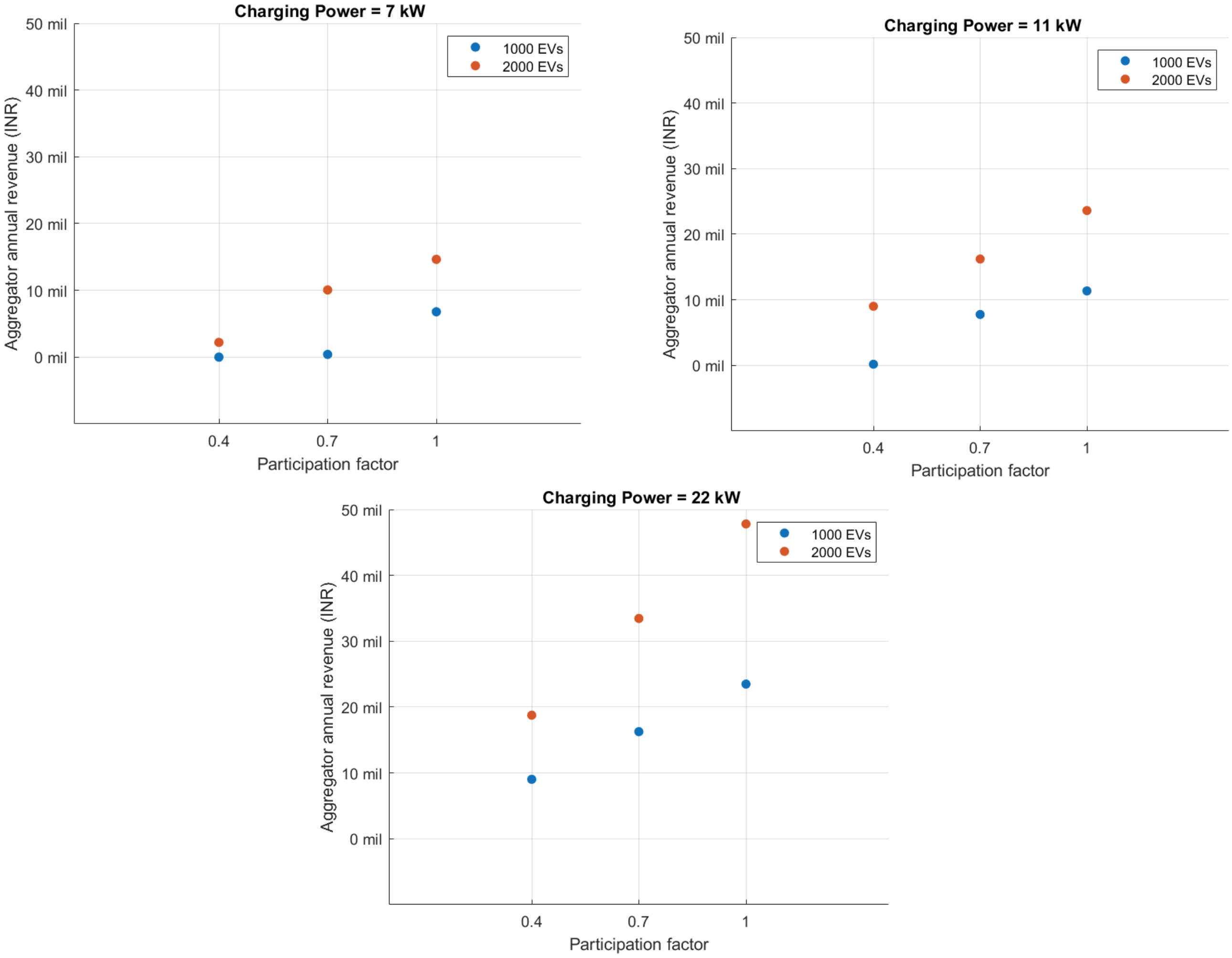

Figure 8:19: Sensitivity of aggregator net revenue to the number of EVs

However, if the EV user is already participating in the service, then the addition of EV users does not increase the revenue made by each user, as now the increased revenue is divided into a higher number of EV users, as shown in Figure 8:20.

Increasing the charging capacity of the EVs would also increase the revenue earned by the aggregator, as shown in Figure 8:21. Here, the relationship is almost linear once the EV aggregator participates in providing the frequency regulation service.

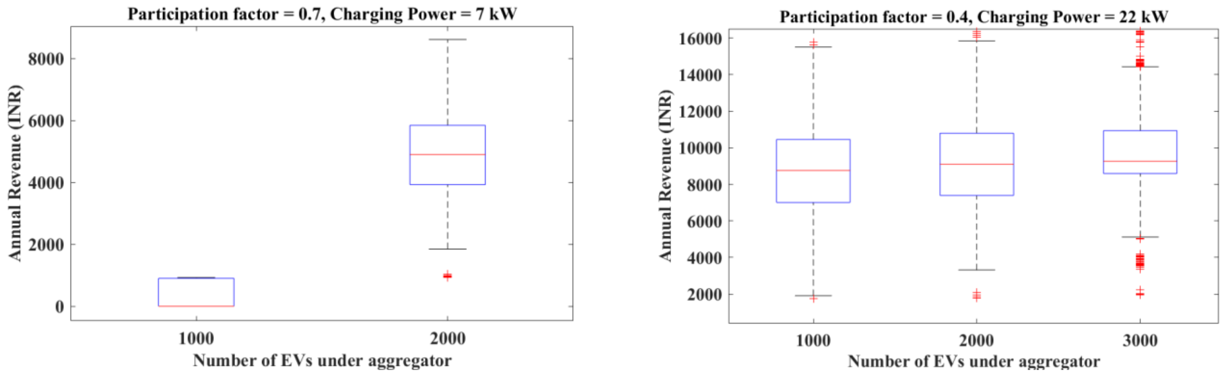

Figure 8:20: Sensitivity of annual revenue earned by each EV user to number of EV users under the aggregator

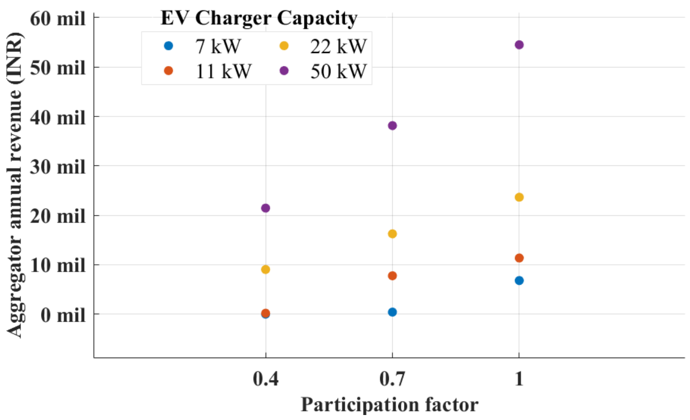

Figure 8:21: Total aggregator revenue for different EV charging power and participation factors

However, looking from a purely economic perspective, the maximum number of charge events happening parallelly is around 250 as shown in Figure 8:8. So, in effect if the aggregator has 1000 vehicles registered, around 250 V2G chargers would be needed to be installed. Based on the power rating of the chargers the total cost is shown in Table 8.2.

Table 8.2: Cost of 250 V2G chargers

Power rating of chargers (kW)	7	11	22	50
Cost of individual chargers	₹ 2,82,000.00	₹ 4,23,000.00	₹ 6,34,500.00	₹ 15,00,000.00
Total Cost	₹7,05,00,000.00	₹ 10,57,50,000.00	₹ 15,86,25,000.00	₹ 37,50,00,000.00

The revenue earned by the aggregator and the economic viability is shown in Table 8.3. From the table, the economic viability scales with the power rating of the chargers can be observed. However, the minimum bid capacity is equally significant.. With lower bid capacity, the revenue that can be earned would increase as the service could then be provided for a wider time duration leading to higher revenue earning potential.

Table 8.3: Economic viability

Power rating of chargers (kW)	7	11	22	50
Annual revenue	₹ 80,00,000.00	₹ 1,10,00,000.00	₹ 2,40,00,000.00	₹ 5,50,00,000.00
NPV considering 10 years operation	₹ 4,91,56,536.85	₹ 11,00,00,000.00	₹ 24,00,00,000.00	₹ 55,00,00,000.00
NPV-Total Cost	₹ -2,13,43,463.15	₹ 42,50,000.00	₹ 8,13,75,000.00	₹ 17,50,00,000.00

Chapter 9. Application of EVs for Peak Load management and Increased Renewable Energy Integration

9.1 Introduction

Distribution companies with EV integration, particularly those having higher EV penetration have started experiencing various technical and economic challenges due to the increased adoption of EVs. Distribution networks are generally designed to accommodate standard demand growth over the years. However, the distribution networks were traditionally not designed to cater to EV load. Therefore, it becomes imperative to provide reinforcement to the existing distribution network and plan new networks to accommodate large-scale EV integration.

However, it's important to highlight that this push for EV adoption is primarily intended to reduce pollution from conventional internal combustion engine (ICE)-based vehicles. Mere transition towards electric mobility alone would not be effective enough if EVs are being charged by power generated from fossil fuel based conventional power plants. Hence, there is a pressing need to encourage EV charging using greener sources of electricity.

This chapter has been structured as follows. First, the modelling of the EV charging behaviour is described in Section 9.2. In Section 9.3, a methodology for EV charging scheduling to achieve the objectives of load levelling and maximum utilization of renewable sources has been discussed, followed by the results of the methodology in Section 9.4. An economic analysis was also carried out in the study and has been described in Section 9.5. The conclusion of the study is presented in Section 9.9.

9.2 EV Modelling

This chapter is focused on smart charging of light-duty EVs to exploit benefits from EV charging, such as peak shaving, valley filling and maximization of renewable energy utilization.

First, the creation of EV profiles with their parameters is presented. The assumptions and modelling steps are discussed. Then, the method for EV charging scheduling is discussed for two different objectives. Different penetration of EV and renewable energy resources are considered as different case studies. Dumb charging and V1G charging are also discussed as base cases for a comparative analysis. Finally, an economic analysis is presented to compare the benefits of V2G charging.

9.2.1 EV Profile generation

Accurate modelling of EV behaviour depends on different parameters, such as arrival time, departure time, battery capacity of EV, initial battery SOC, desired SOC at time of departure and type of EV charger used by each EV.

9.2.1.1 EV user behaviour

Two types of EV chargers have been considered in this study: residential EV chargers and workplace EV chargers. The EV travel pattern for residential charging is derived from the probabilistic arrival and departure pattern used by Zheng et al[93]. For residential charging, the standard deviation and mean for arrival are taken as 2.06 h and 19.55 h and for departure 0.92 h and 7.25 h, respectively. Workplace charging behaviour is taken from publicly available Adaptive Charging Networks (ACN) datasets[94].

The arrival and departure time histograms are shown in Figure 9:1. From Figure 9:1(a), we can see that for residential charging, the arrival time for EV is late in the afternoon to the evening, while departure starts early morning till the afternoon, as shown in Figure 9:1(b). In the case of workplace charging, the arrival and departure time is set according to office working hours. The maximum number of EVs arrives at 8 AM, as shown in Figure 9:1(c). The departure time is in the evening, as seen in Figure 9:1(d). The combined

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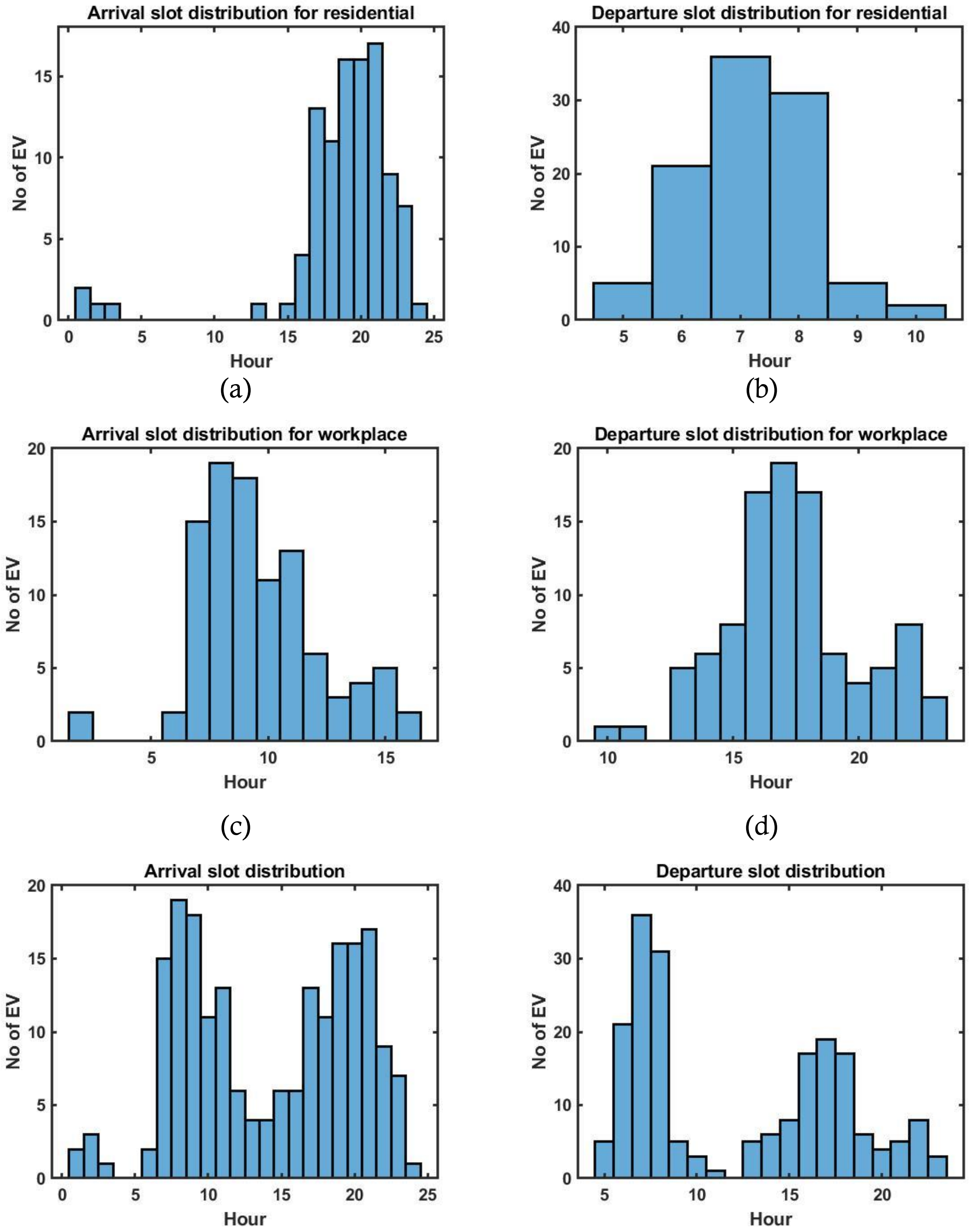
[93] Zheng, Yanchong, et al. "A systematic methodology for mid-and-long term electric vehicle charging load forecasting: The case study of Shenzhen, China." Sustainable Cities and Society 56 (2020): 102084.

[94] “ACN data”, Caltech. [Online] available: https://ev.caltech.edu/dataset

arrival and departure distribution can be seen in Figure 9:1(e) and Figure 9:1(f). The total number of EVs available at any instant can be seen in Figure 9:2.



(a)

(b)

(c)

(d)

(e)

(f)

Figure 9:1 Histogram plots shown for (a) arrival of EVs for residential charging (b) departure of EVs from residential charging (c) arrival of EVs for workplace charging (d) departure of EVs for workplace charging (e) combined arrival for residential and workplace charging (f) combined departure for residential and workplace charging

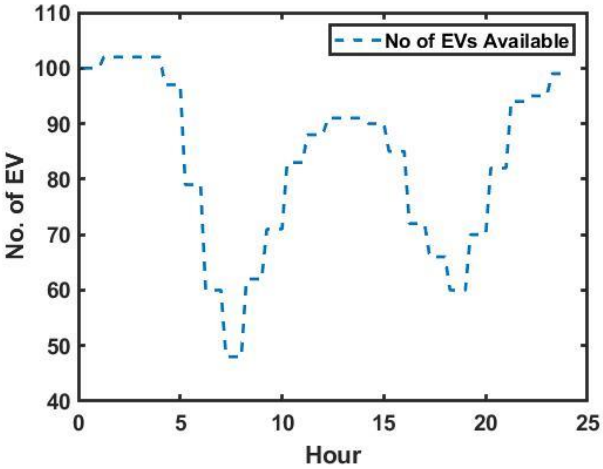


Figure 9:2 EV availability

Apart from these charging behaviors, in the case of V2G charging, it is considered that benefits from V2G charging will encourage EV owners to make their EV available during evening peak hours. To consider this effect, an additional 25% of EV owners, who were previously not connected to a charger, are considered to make their EVs available during evening peaks, i.e., 18:00 h - 22:00 h. The modified availability of EV at each interval is shown in Figure 9:3.

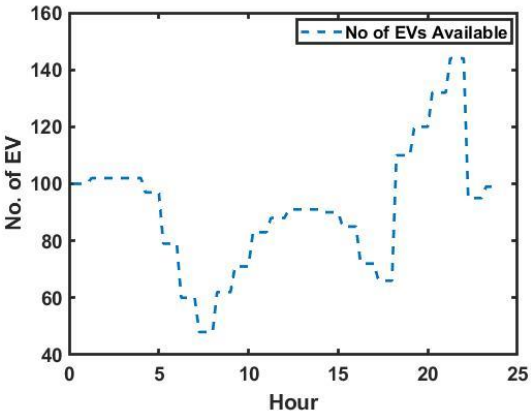


Figure 9:3 Enhanced EV availability during evening peak

9.2.1.2 Charging data

The battery capacity of the EV plays a crucial role in determining the potential grid support from EVs. A market survey on the size of EV batteries in India for 4-wheeler car segment has shown that their capacity lies in the range of 30 to 50 kWh. Therefore, in the study, the battery capacity for all the EVs has been randomly distributed in this range.

In India, 3.3 kW, 7 kW, 22 kW, and 50 kW (DC) chargers are mostly available. For this study, it was considered that 20% of all EVs will be charged by 3.3-kW chargers, 40% by 7-kW chargers, 20% by 22-kW chargers, and the rest 10% by 50-kW chargers. These chargers are again randomly distributed between all the EVs.

9.2.1.3 State of charge

Different battery degradation studies[95] have concluded that the battery life of an EV is maximized by maintaining the SoC of the battery between 20 and 80%. The state of charge is defined as the ratio of the available capacity $E(t)$ and the maximum possible charge that can be stored in a battery or the nominal battery capacity E_n.

$$SOC(t) = \frac{E(t)}{E_n} \times 100\% \qquad \text{Eq. 12}$$

The initial SOC of each EV is therefore considered between 30% to 50%. This implies that the EVs will be connected for charging with this value of SOC. Similarly, the desired SOC for each EV is considered randomly distributed between 80% to 85%. The schedule for EVs will be designed such that all EVs must reach their desired value of SOC before the end of the schedule period.

9.2.1.4 EV penetration

Different EV penetration levels were considered in the study. 100% EV penetration implies that each household in the system owns an EV (leading to 200 EVs in the system, as the number of households considered in the study is 200).

9.2.1.5 EV profile generation

Taking into consideration all the above parameters, an EV profile needs to be generated, which contains information on all these EV parameters. IDs are assigned to all the EVs considered with the arrival time, departure time, initial SOC, and desired SOC. A charger is assigned to each EV randomly. This EV profile is being used to generate the EV schedule.

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[95] Jiang, Jiuchun, et al. "Optimized operating range for large-format LiFePO4/graphite batteries." *Journal of The Electrochemical Society* 161.3 (2013): A336.

9.2.2 Load Curve

The load curve was obtained from the eMARC website maintained by Prayas (Energy Group)[96]. Minute-wise data was recorded by the eMARC meters installed in 115 homes in Maharashtra and Uttar Pradesh. The analysis period is from January 2018 to June 2020. The data in 15-min intervals of active power (kW) for households in Pune city was and was scaled up to consider the household demand of 200 households. The resulting baseload curve is shown in Figure 9:4.

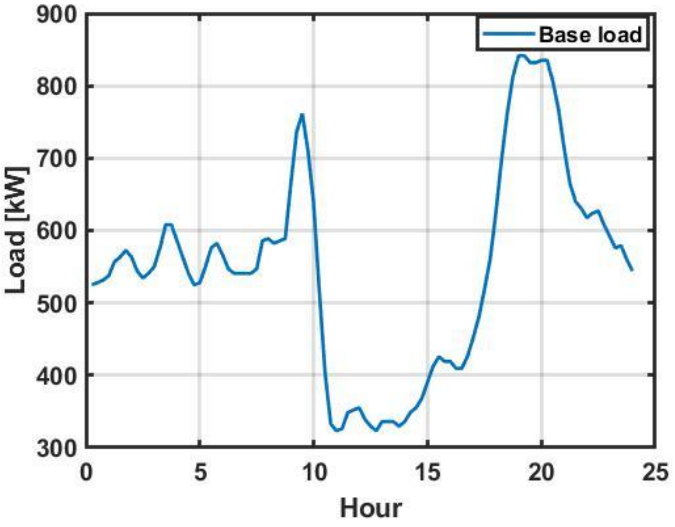

Figure 9:4 Base load curve

9.2.3 Solar Photovoltaic (PV) penetration

Like EV penetration, a range of solar PV power penetration was considered. A 100% PV penetration implies that the annual household energy demand was supplied by solar PV units. The cumulative rating of PV modules in such a case was calculated as follows:

$$SPV_{cap} = \frac{E}{0.6 \times 8 \times No.of\ days} \qquad \text{Eq. 13}$$

Where, SPV_{cap} is the required capacity of solar PV generating units, and E is the total annual energy demand that needs to be supplied by the PV units. Here, the number of days has been assumed as 365, with an average of 8 hours of sunlight per day. The factor of 0.6

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[96] Prayas, 'Monitoring and analysis of residential electricity consumption', http://emarc.watchyourpower.org/

considers the impact of rainy/cloudy days on the total energy generation by the PV plant annually[97]. The PV generation considered for one day is shown in Figure 9:5.

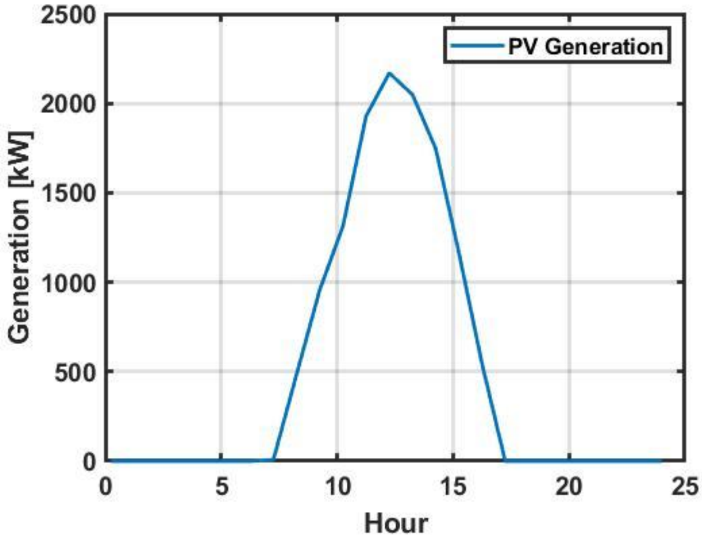

Figure 9:5 PV generation profile

9.2.4 EV Scheduling

The EV schedule is prepared based on the parameters mentioned above. The schedule matrix is populated so that when a particular EV is available at that slot, the matrix element has a value of '1'; when the EV is unavailable, the value is '0'. An example can be seen in Figure 9:6.

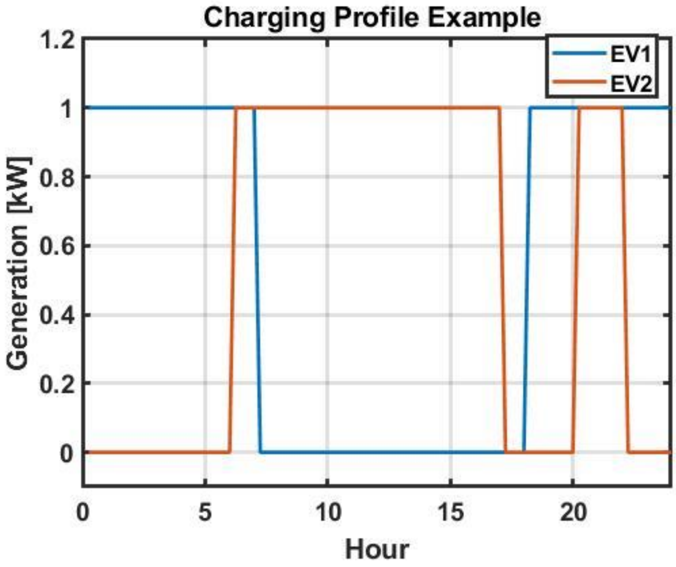

Figure 9:6 Charging profiles example with EV1 charging once while EV2 charging twice

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[97] EcoSoch, "Solar generation in Bangalore". https://www.ecosoch.com/solar-generation-in-bangalore/

9.3 Optimum Scheduling of EV

The scheduling algorithm is programmed in MATLAB. Convex optimization was used to solve the optimization problem. The constraints taken while scheduling the EVs are given below,

- C1: Power balance: $P_{grid} = P_{EV} + P_{base}$
- C2: Maximum and minimum charging limits: $-P_{rate} \leq P_{EV,t} \leq P_{rate}$
- C3: SOC limits: $0.2 \leq SOC \leq 0.85$
- C4: Charging Completion: $E_{EV\_\mathrm{ini}} + \sum_{t=1}^{n} P_{EV} \times t \geq E_{EV\_req}$

Here, C1 maintains the load balance in the system where, P_{grid} is the total power drawn from the grid, P_{EV} is the power drawn by EVs (sign convention of EVs: positive when EV acts as a load and negative when EV acts as a generator), P_{base} is the base load in the system. C2 limits the charging/discharging power of each EV where, P_{rate} is the maximum charging/discharging capability of the EV, constraint C3 defines the SoC limits of each EV and constraint C4 explains the minimum energy required by each EV for the completion of charging.

In the following section of the study, two different objectives are considered as follows:

a. Load Leveling
b. RE utilization maximization

For each objective, a separate objective function has been defined.

9.3.1 Load Leveling

The objective in this scenario is to reduce the peak to the average ratio for the system load, such that evening peaks can be reduced and valleys in the afternoon and night can be filled. This can be done if more EVs are charged during the valley periods and discharged (performing vehicle to grid operation) during the peak load periods. To fulfil this objective, a virtual pricing signal (VPS) is generated. This VPS is proportional to the baseload curve, so when the load is high, VPS is high and vice versa. Thus, our objective function is defined to reduce VPS. Hence, during valley hours, when VPS is low, more EVs are encouraged to charge, and during peak hours, the vehicle battery is discharged to maximize the virtual profit. The mathematical representation of an objective function is:

$$minimize \{\sum_{t=1}^{n} C_t \times P_{EV,t}\} \qquad \text{Eq. 14}$$

$$C_t = k \times Load_{Base} \qquad \text{Eq. 15}$$

Where,

C_t is the VPS at time interval 't'

$P_{EV,t}$ is the net EV load at that time interval 't', $P_{EV,t} = \sum_{i=1}^{N} P_{EV_i,t}$

k is a proportionality constant and $Load_{Base}$is the base load of the system.

9.3.2 RE utilization maximization

In this scenario, the objective is to utilise the maximum possible PV generation. So the objective function has been modified such that most of the available EVs are charged when PV generation is available. To account for this, the VPS signal has been modified to be equal to the difference between base load and PV generation as given in Eq. 16. So, whenever the PV is available, the VPS signal decreases to a lower value and encourages EVs to charge in the duration. The objective function will remain the same as Eq. 14, except the value of C_t.

$$C_t = k \times (Load_{Base} - RE) \qquad \text{Eq. 16}$$

9.4 Results

Using the above optimization framework, an EV schedule is obtained for all the EVs. The result analysis suggest how much load each EV must have in each time slot throughout the day. At the end of the day, the SOC of each EV must be greater than the required SOC. Also, it must be verified that the SOC must not go below 0.2 or above 0.85 at any slots.

9.4.1 Results for load levelling

Figure 9:7 presents the net load due to EV charging at a 100% penetration level. It is evident that during morning and evening peaks, the vehicles are supplying power to the load (shown as negative power flow), while at the valleys, these EVs are getting charged. It can be seen more clearly in Figure 9:8, which shows the base and total load (base load+EV load).

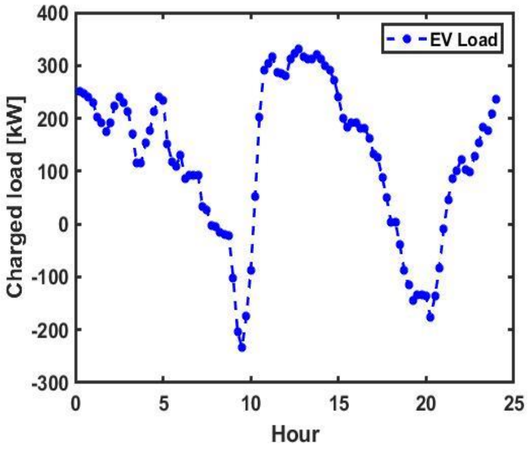


Figure 9:7: Charging load of EVs

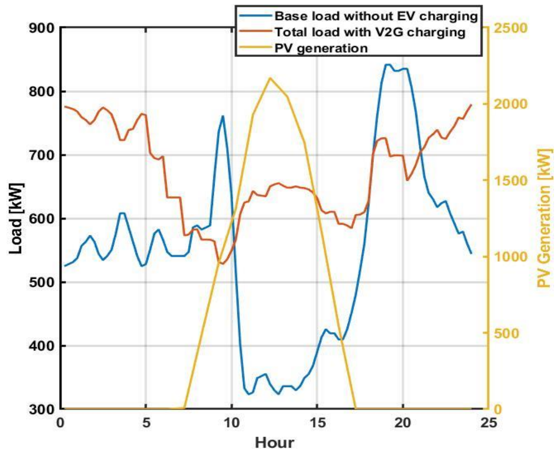


Figure 9:8 Load Curves

Figure 9:9 shows the SOC evolution of randomly selected 10 EVs. It demonstrates that all the EVs are reaching their desired SOC level without crossing the limits at any point in time.

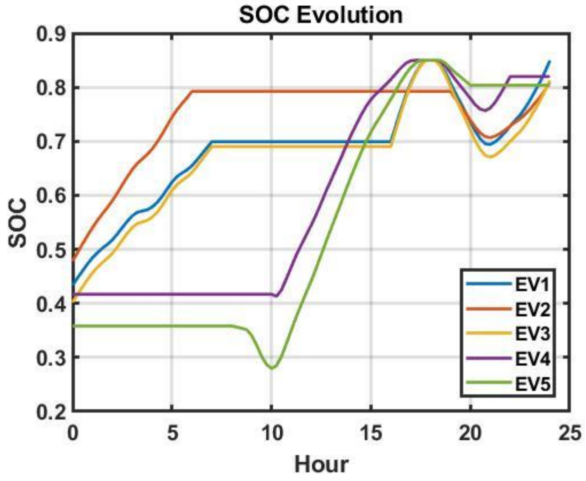
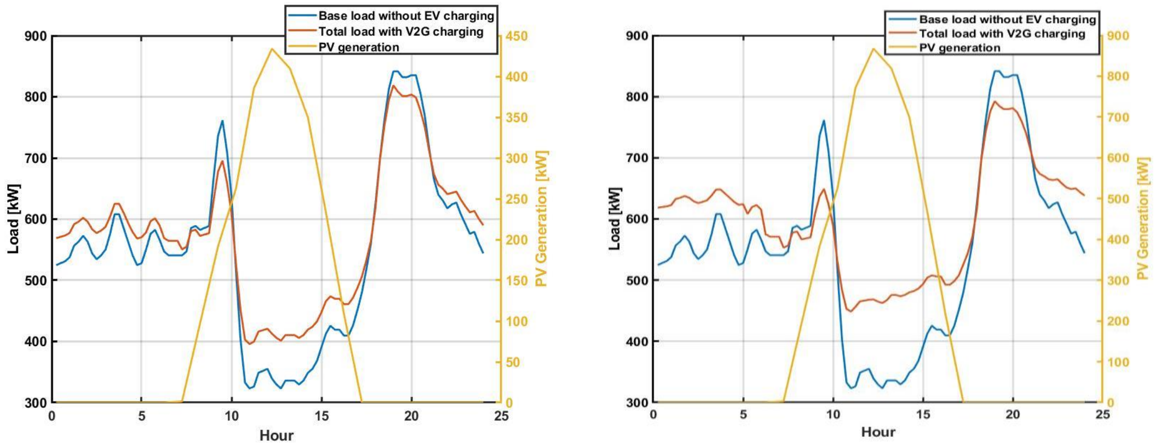
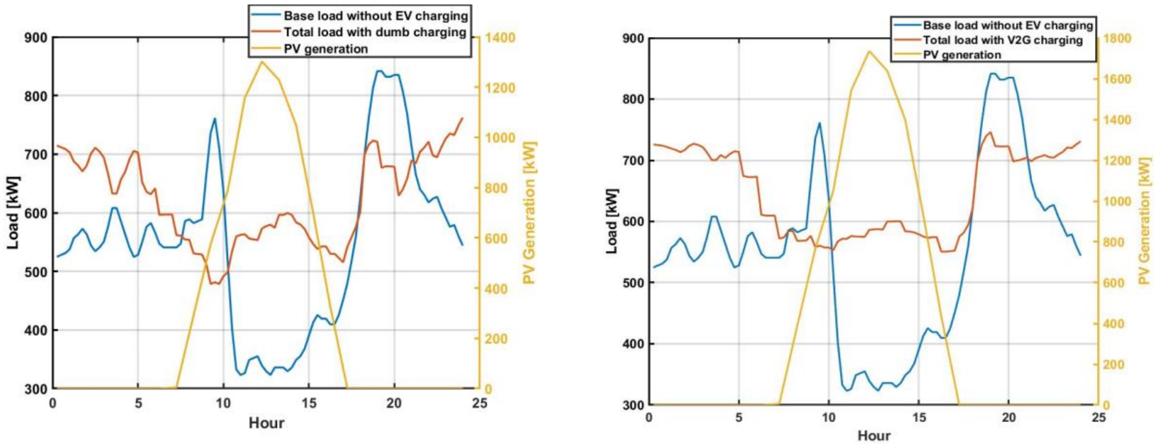


Figure 9:9 SOC evolution



(a) 20% penetration

(b) 40% penetration



(c) 60% penetration

(d) 80% penetration

Figure 9:10 Load profiles at different EV and PV penetration levels

Figure 9:10 shows the load profile for different penetration of EV and PV. From these figures, it can be observed that the EV load has helped flatten the load curve by supplying load during peak hours and charging EVs during valley periods.

For verifying the effectiveness of V2G charging in load levelling, peak to average ratio(PAR) is used. The peak-to-average ratio[98] is defined as:

$$PAR = \frac{L_{max}}{L_{av}} \quad \text{Eq. 17}$$

where the average load is defined by Eq. 18 and peak load by Eq. 19:

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[98] Liu, Yi, et al. "Peak-to-average ratio constrained demand-side management with consumer's preference in residential smart grid." IEEE Journal of Selected Topics in Signal Processing 8.6 (2014): 1084-1097.

$$L_{av} = \frac{1}{T}\sum_{t\in T} L_t \qquad \text{Eq. 18}$$

$$L_{max} = \max_{t\in T} L_t \qquad \text{Eq. 19}$$

Figure 9:11 shows the PAR ratio at different penetration level of RE and EV. The 0% penetration signifies the case when no EV load is present in the system. From Figure 9:11, it can be observed that the PAR value is reduced as EV penetration increases. This is because more number of EV are now available for load management. Also, it can be observed that V2G is more effective in reducing PAR compared to V1G since during afternoon and evening peaks the vehicle is supplying power to the load, reducing the load demand and the peak load of the system during these periods. Moreover, there is negligible impact of RE penetration on PAR ratio since the objective has been to level the load, not increase RE utilization.

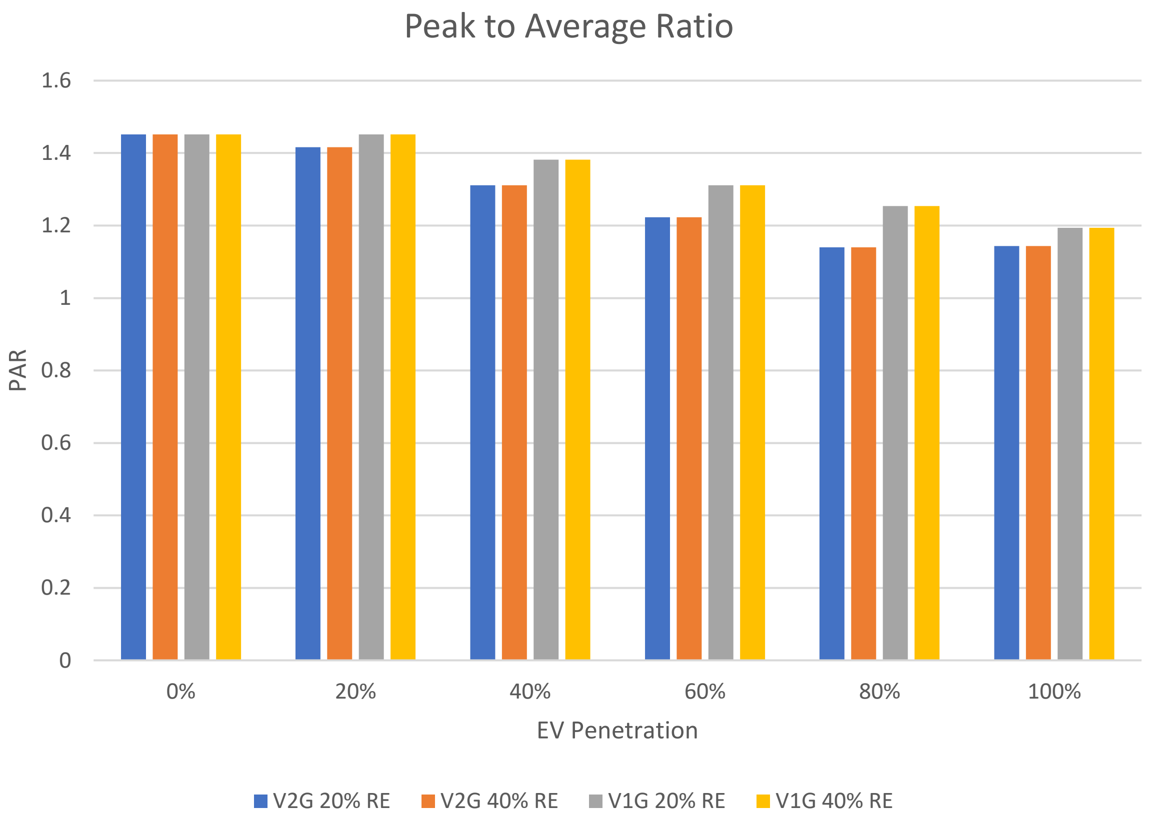


Figure 9:11: Peak to average ratio at different penetration levels of RE and EV

9.4.2 Results for RE utilization maximization

To achieve the objective of RE utilization maximization, EV charging must be scheduled so that maximum EVs must be charged when solar PV is available. Using the objective function in Eq. 16, the EV schedule is generated. Figure 9:12 shows the EV load at 100% EV penetration.

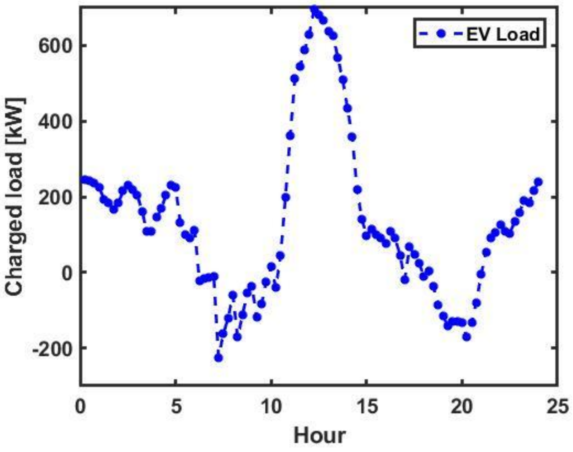


Figure 9:12 Charging load of EVs

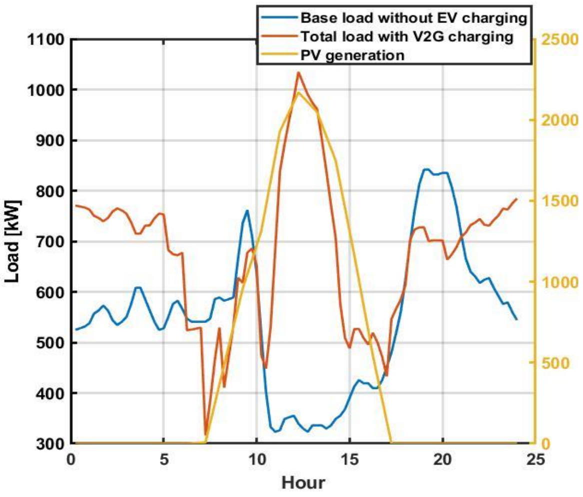


Figure 9:13 Load Curves

From Figure 9:12, it is clear that the maximum EV load is catered during the hours when PV is available, thereby enabling the RE based charging during off-peak load hours. Figure 9:13 shows the base load and net load curve. It is evident from the figure that the optimisation framework attempts to schedule the maximum load during the period of PV generation. The SOC variation of 10 random EVs is shown in Figure 9:14. The SOC is not violating any applicable constraints and reaches the desired optimum at the end of the day. The load curves at different EV and PV penetration are shown in Figure 9:15.

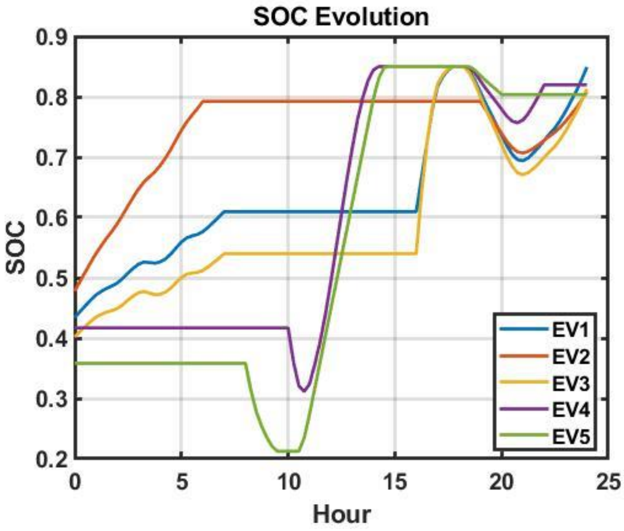
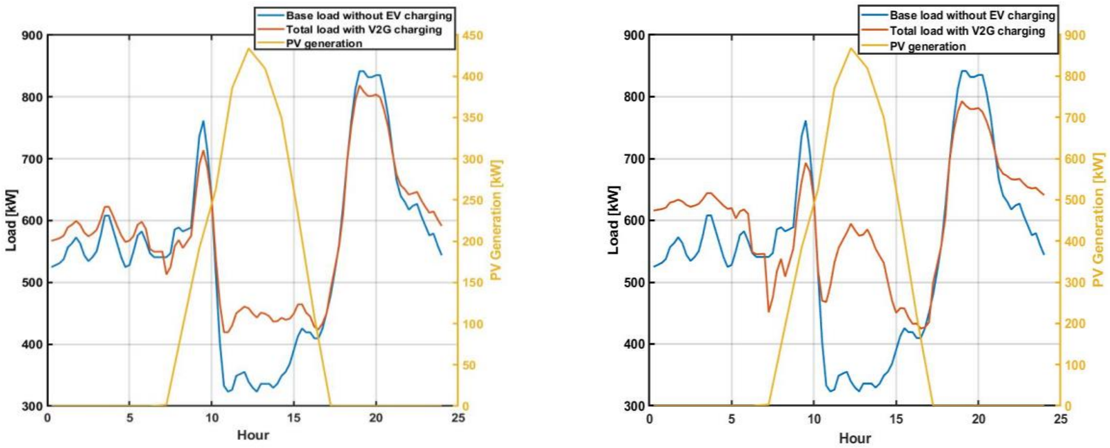
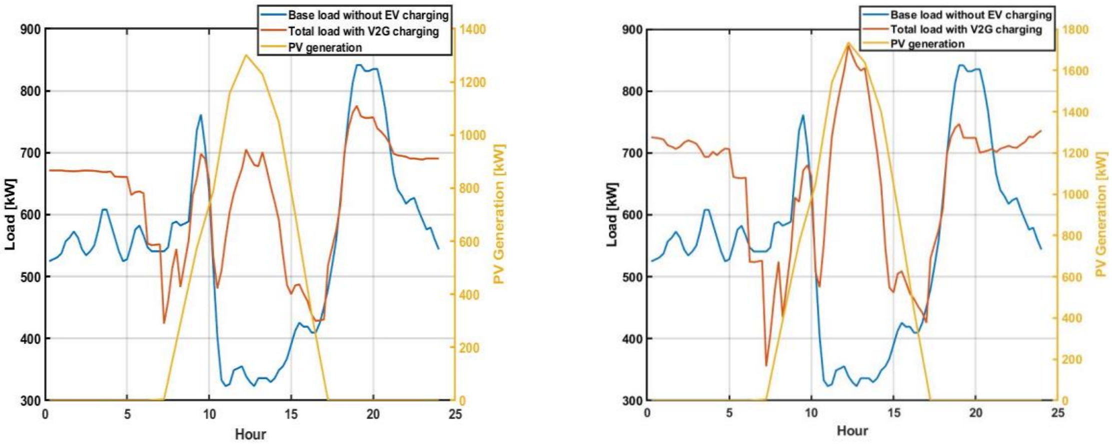


Figure 9:14 SOC evolution



(a) 20% penetration

(b) 40% penetration



(c) 60% penetration

(d) 80% penetration

Figure 9:15 Load profiles at different EV and PV penetration levels

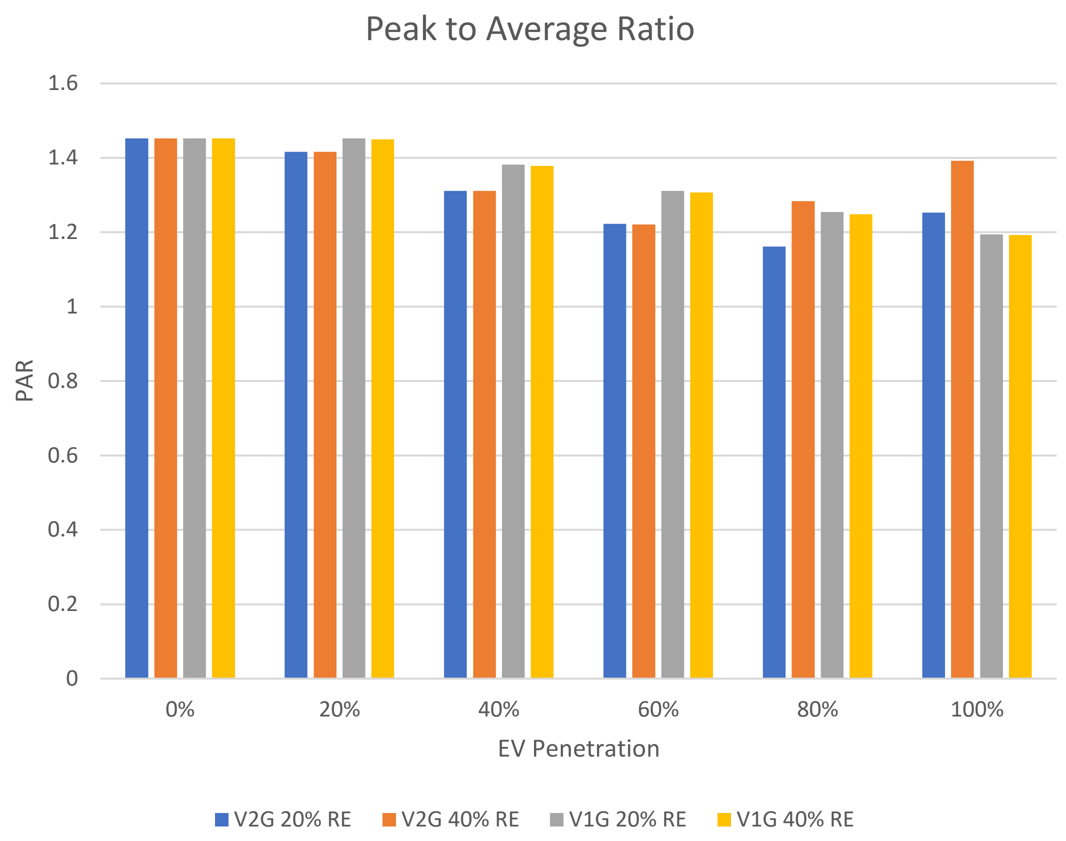


Figure 9:16: Peak-to-average ratio

Figure 9:16 shows the PAR for this scenario. The trend of PAR between V1G and V2G is similar to the previous cases. PAR is lower in the case of V2G up to 60% EV penetration. However, for 80% and 100% EV penetration, the PAR is higher for V2G than V1G. To utilize the maximum possible renewable energy, the total load in the system becomes higher than the base case during periods of high PV generation, i.e., around 1 PM. Due to this increase in peak load, the PAR increases. As the penetration of EV and PV increases from 80% to 100%, more PV generation is available, and more vehicles are known to be charged, leading to a further increase in PAR. More the RE penetration, the higher will be peak load, and the higher will be PAR.

Figure 9:17 shows the annual renewable energy curtailed in V1G and V2G schemes. It is evident that V2G utilizes more PV than V1G, reducing the curtailment. In both cases, the number of vehicles and the distance traveled are the same, so the energy requirement must be equal. However, in the V2G scheme, the vehicle provides energy to the load during peak hours. Hence, they need more energy to reach the desired SOC at the end of the day. This increased requirement is fulfilled during the RE availability hours, reducing curtailment in the V2G scheme.

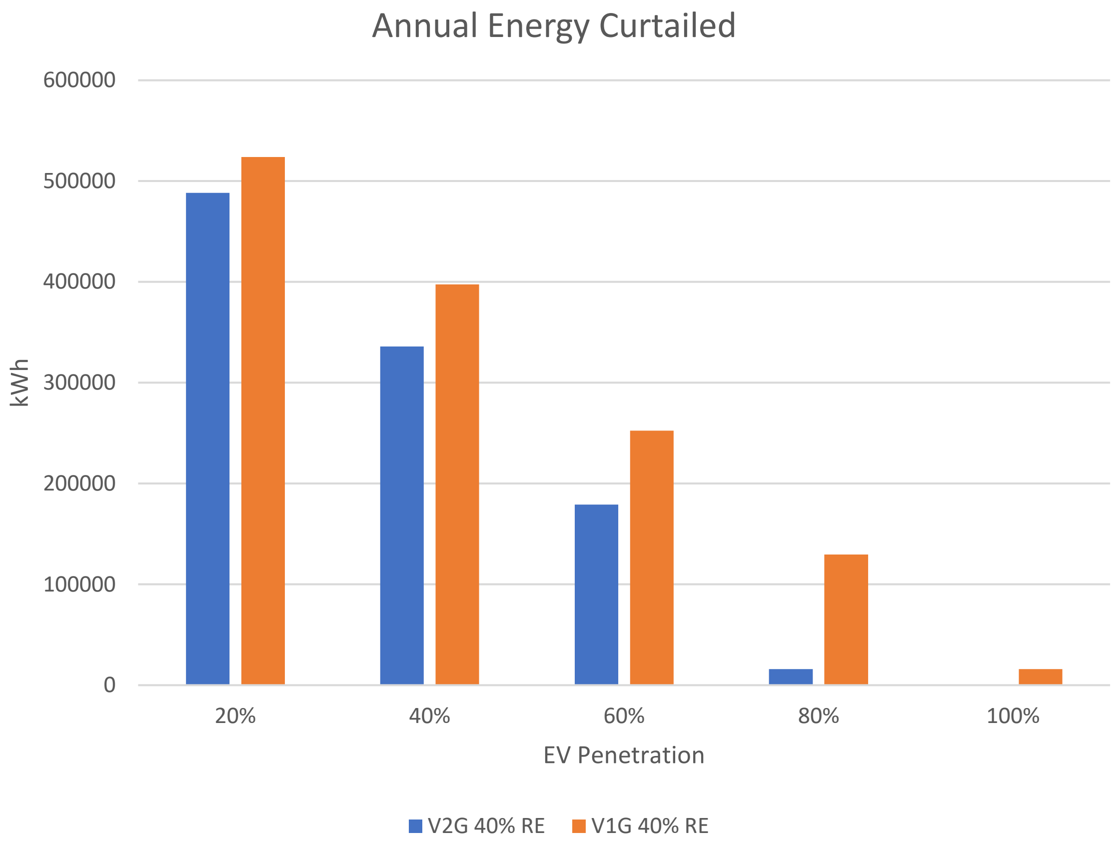


Figure 9:17 Annual curtailed energy

9.5 Economic analysis

Section 9.4 shows that V2G is technically superior to V1G in both load leveling and RE utilization maximization. Nevertheless, economic analysis is essential to contemplate the acceptance of any new technology. Therefore, cost-benefit analysis has been conducted to compare the V1G and V2G technologies.

The cost of EV charging can be segregated into capital and operational costs. In this study, the capital cost includes the cost of EV chargers and the cost of PV panels. The infrastructure cost, e.g., the cost of land and building, is excluded from this analysis. Similarly, only the cost of electricity purchased has been considered in operational cost. The labour cost and maintenance cost has been excluded from the study.

9.5.1 Capital cost

The cost of energy from solar PV installations is considered to be INR 50,000 (EUR 588) per kW_p[99]. The cost of each charger is given in Table 9.1.

Table 9.1: Capital cost of chargers [100, 101]

Equipment	Capital Cost (INR/EUR) For V1G charger	Capital Cost (INR/EUR) For V2G charger
3.3 kW charger	11,000/ 129.48	40,700/ 479.10
7 kW charger	42,000/ 494.41	1,55,400/ 1829
22 kW AC charger	60,000/ 706.30	2,22,000/ 2613.30
50 kW DC charger	11,00,000/ 12,948.80	15,00,000/ 17,657

The total number of chargers is assumed to be 15 more than the maximum number of EVs charging simultaneously in each penetration level.

The annualized capital cost (ACC) is a parameter frequently used in economic studies and can be calculated using Eq. 20. Life cycle costing is the process by which the owners of an asset compile all the costs that this asset will incur throughout its lifetime.

$$ACC = Capital\ Cost \times \left(\frac{d(1+d)^n}{(1+d)^n - 1}\right) \qquad \text{Eq. 20}$$

ACC for V2G and V1G is shown in Figure 9:18 and Figure 9:19 respectively. The ACC for V2G is higher than V1G due to the higher cost of the V2G charger.

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[99] Kenbrooksolar, "2kW Solar System Price and Details for home in India" https://kenbrooksolar.com/system/2kw-solar-system-price

[100] Michael Nicholas, "Estimating Electric Vehicle Charging Infrastructure Costs across Major U.S. Metropolitan Areas" (ICCT, August 2019)

[101] Huber, D., De Clerck, Q. De Cauwer, C., Sapountzoglou, N.Coosemans, T., Messagie, M. 'Vehicle to Grid Impacts on the Total Cost of Ownership for Electric Vehicle Drivers'. World Electr. Veh. J. 2021, 12, 236

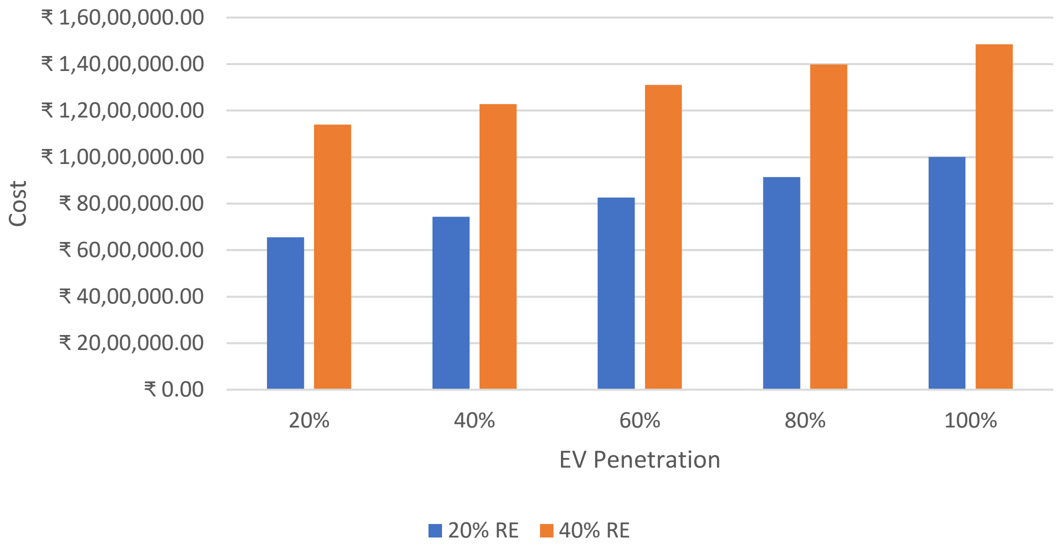

Figure 9:18: Annualized Capital cost for V2G charger

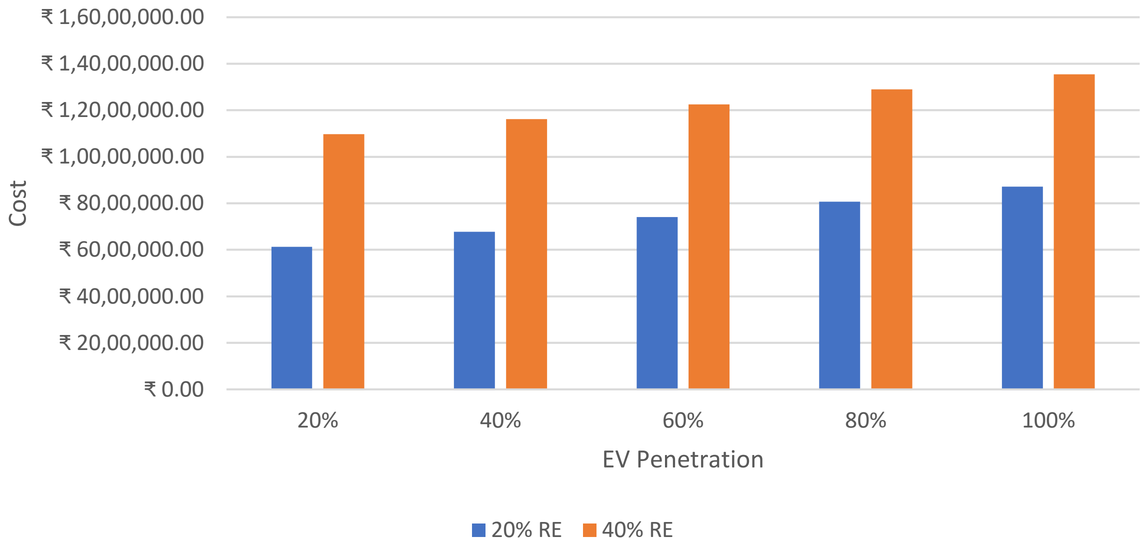

Figure 9:19 Annualized Capital cost for V1G charger

9.5.2 Operating Cost

To calculate the operating costs, three different tariff structures have been used.

- Time of day tariff (TOD)
- India Energy Exchange (IEX) rates
- Residential tariff structure

9.5.3 Time of day tariff

The first tariff structure is the time-of-day (TOD) tariff for Maharashtra[102], given in Figure 9:20.

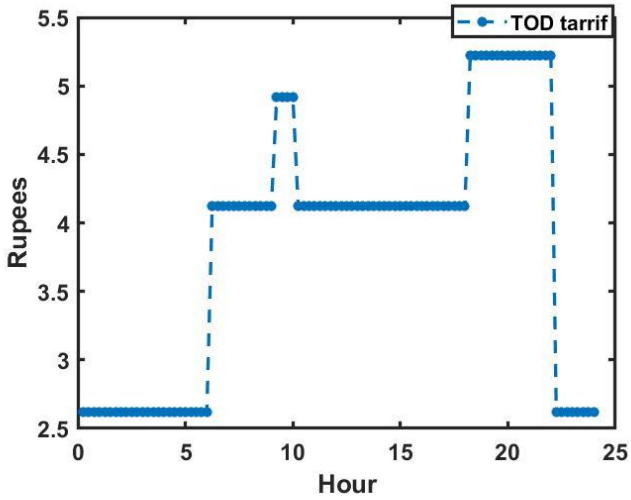

Figure 9:20 Time of Day tariff

Using the TOD tariff, the system's annual operating cost is calculated at different penetration levels. It is considered that the PV is utilized locally without any operational cost, and the excess energy generated is sold to the distribution company at the exact cost as the energy purchased from the grid. The annual operating cost and savings for utilizing V2G instead of V1G are shown in Figure 9:21 and 9:22

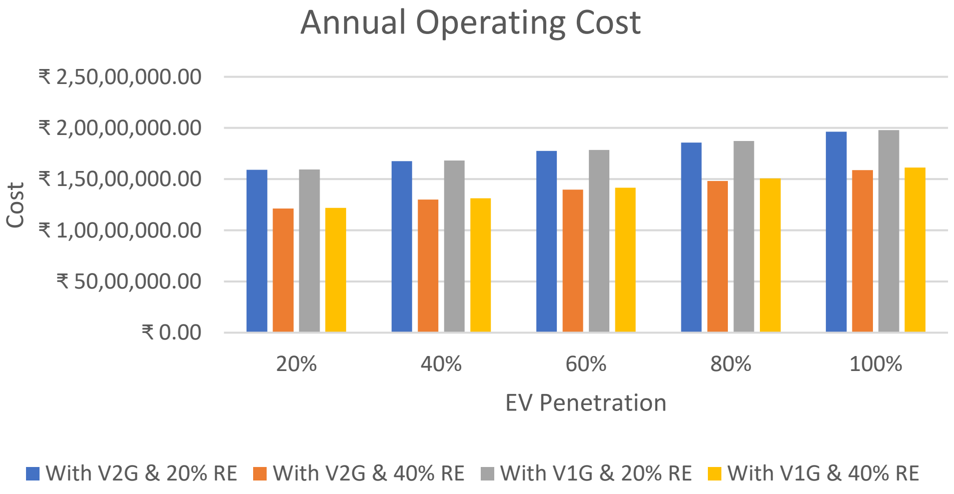

Figure 9:21 Annual operating Cost

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[102] Maharashtra Electricity Regulatory Commission, 'Revision of Electricity Tariff w.e.f. 1st April 2020 and implementation thereof', 3rd April, 2020

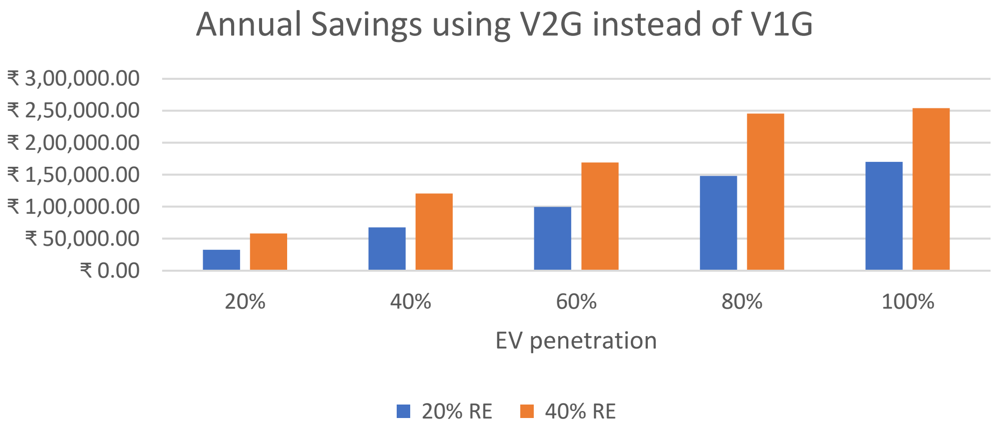

Figure 9:22 Annual savings using V2G instead of V1G.

From Figure 9.21,it can be seen that a higher RE penetration reduces the annual cost of operation as it has been considered that RE generation only has a capital cost component. Also, the operating cost increases with an increase in penetration as more energy is required to charge more vehicles. Figure 9*:22* represents the annual cost savings for using V2G instead of V1G. With a higher penetration, the savings grow with the capability to utilize more RE growing further. However, between 80% and 100% penetration, there is comparatively less growth in savings as an increasing number of EVs beyond 80% gives rise to demand higher than what can be fulfilled by increased PV generation.

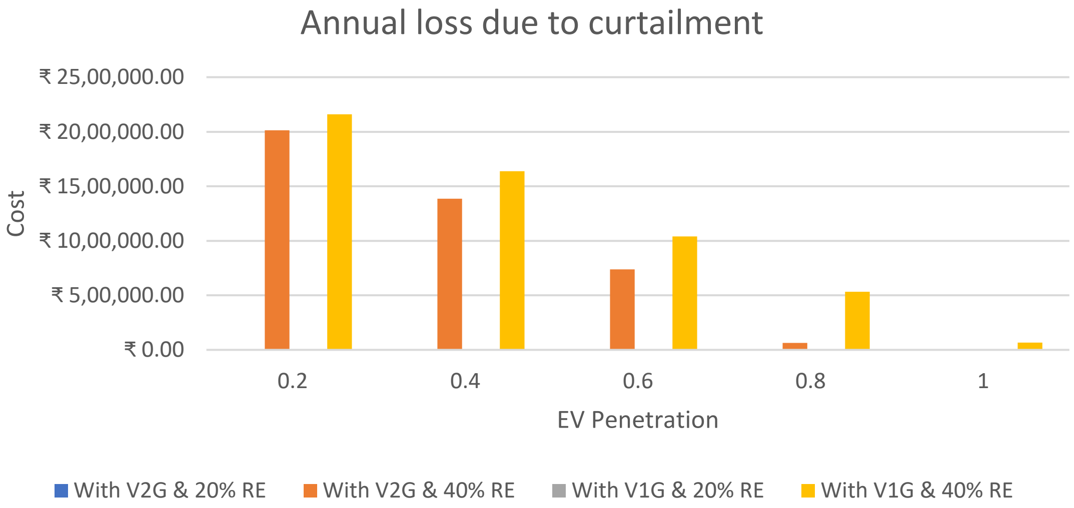

Figure 9:23 Annual operating cost loss due to curtailment

Figure 9:23 shows the annual loss due to curtailment. The loss reduces with an increase in EV penetration which signifies the importance of co-planning RE and PV resources, so they can complement each other as losses can be reduced.

9.5.4 Using IEX prices[103]

The IEX price for the Maharashtra region is shown in Figure 9.24

IEX rates are higher than tariff, and hence the operating cost is also higher as seen in Figure 9:25. Figure 9:26 represents the annual saving in costs by using V2G compared to V1G.

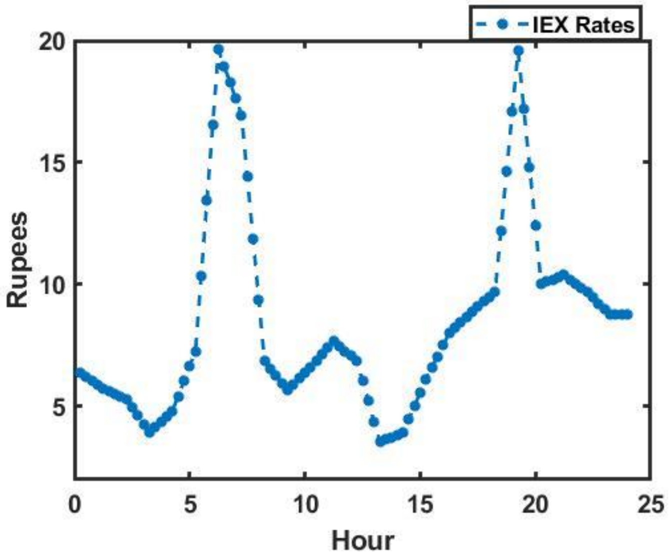

Figure 9:24 IEX tariff rates

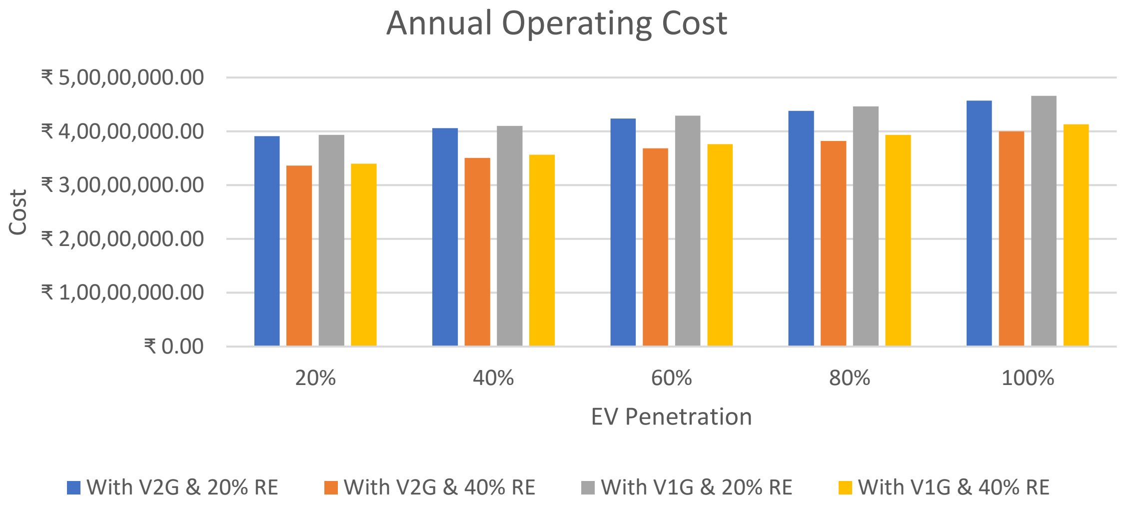

Figure 9:25 Annual operating cost

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[103] IEX, 'Day Ahead Market, Area Prices'. [online] available: https://www.iexindia.com/marketdata/areaprice.aspx

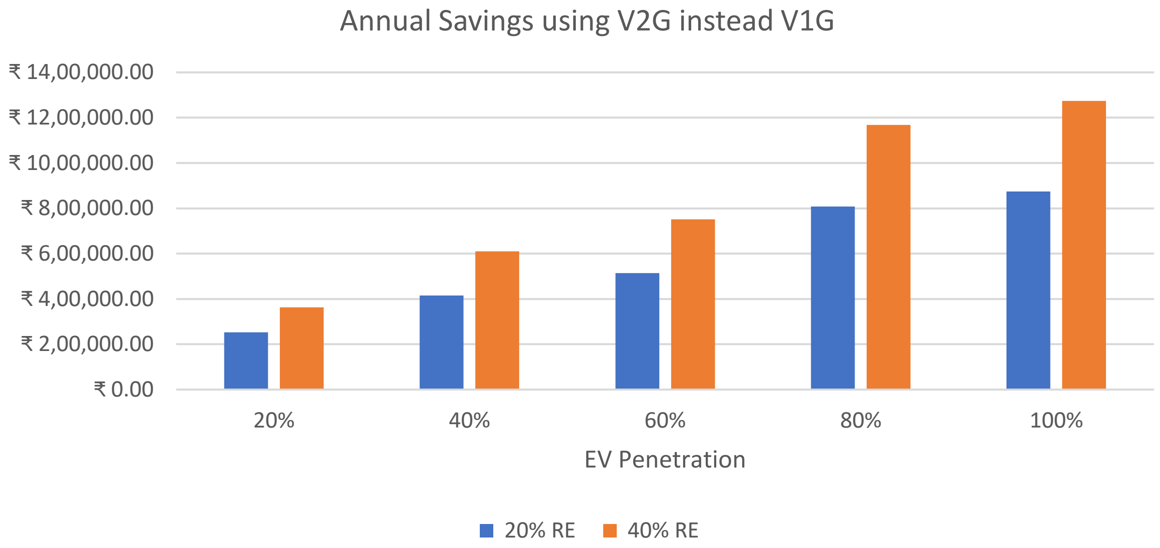

Figure 9:26 Annual savings using V2G instead V1G.

9.5.5 Using California Time-of-Use tariff[104]

The pattern for the residential rates is adopted from The Pacific Gas and Electric Company (PG&E). In this tariff structure, the rate is high during evening peak and low during rest of the day. This tariff structure is shown in Figure 9*:27*.

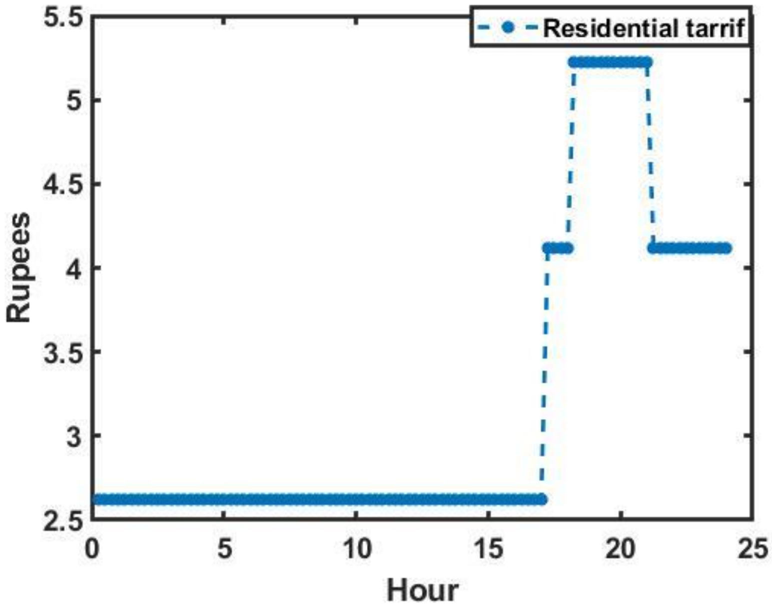

Figure 9:27 Residential tariff rate

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[104] PG&E, 'Electric Vehicle (EV) rate plans', https://www.pge.com/en_US/residential/rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page?

Similar to section 9.5.3 and 9.5.4 the annual operating cost and annual savings are shown in and, respectively. Here, the annual savings are less (Figure 9:29) compared to the tariff structure of IEX (Figure 9:*26*) because V2G is associated with reduced evening peaks compared to V1G, where evening peaks remain intact, and the cost savings cannot be achieved in the morning peak period.

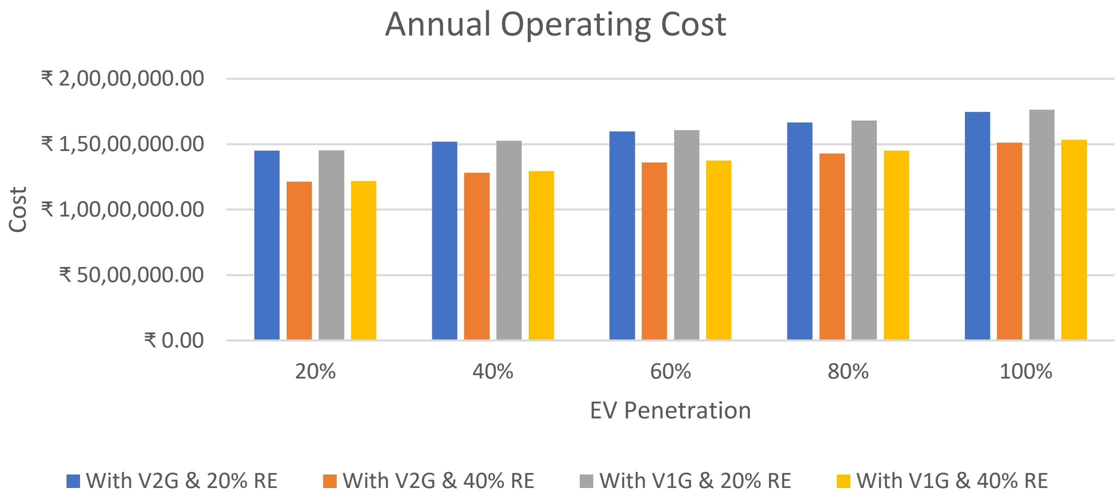

Figure 9:28 Annual Operating Cost

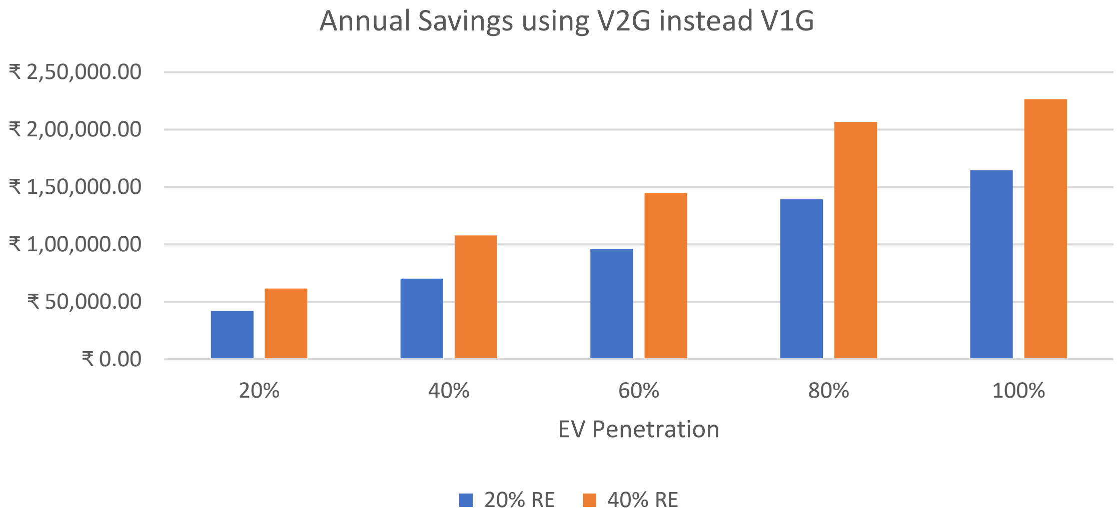

Figure 9:29 Annual savings using V2G instead of V1G

9.6 Annualized Life cycle cost

ALCC include the operation and well as capital cost of the infrastructure. Other cost such as maintainance cost, labour cost, cost of land etc are excluded from the study. Figure 9:30 shows the ALCC for the charging infrastructure.

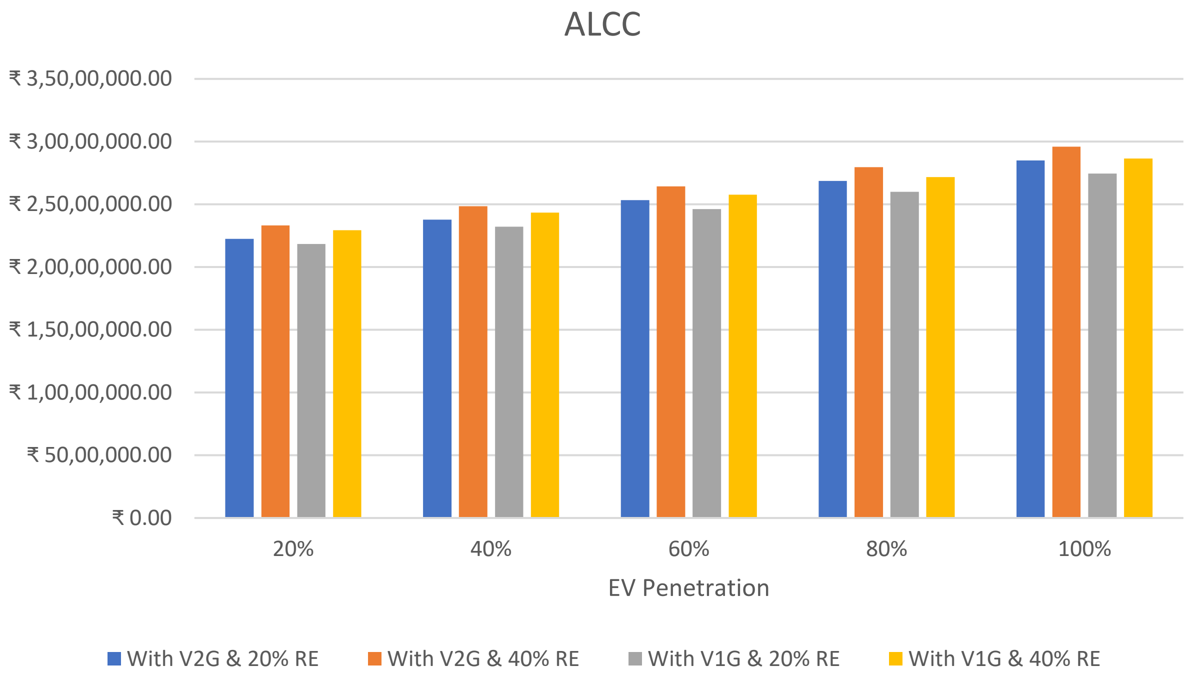

Figure 9:30 Annualized life cycle cost

From Figure 9:30, it is observed that V2G appears to be more costly than V1G. This is because of the higher capital cost of V2G chargers compared to V1G chargers. As the cost of V2G charging falls due to increased technology development, it can become more economical than V1G. Also, this study has not taken into account the cost-benefit of V2G in utilizing more RE, thereby reducing curtailment.

Another case study is performed to clearly understand the involvement of the cost of RE in the above calculated ALCC. Here, it has been assumed that the RE source, i.e., solar PV generating unit (rooftop PV), is already installed in the charging station premises, and the only investment required is that for the charger. For this scenario, the ALCC is shown in Figure 9:31.

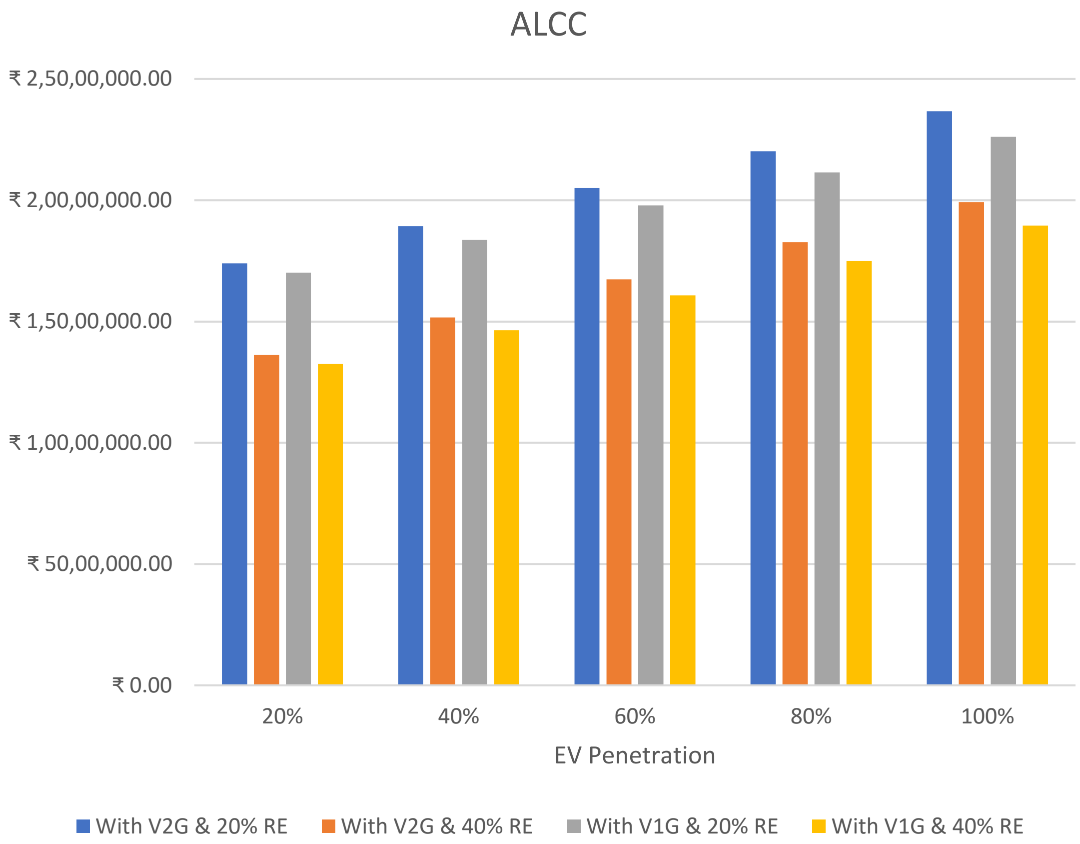

Figure 9:31 Annualize life cycle cost excluding solar PV installation cost

As expected, the overall ALCC reduces, and the ALCC for 20% RE penetration is higher than previous case where it was comparatively lower with V2G and 40% RE penetration. This is because, with the elimination of the capital cost of RE, increased RE penetration is leading to higher savings. However, the ALCC for V2G remains higher than V1G.

9.7 Case study: Effect of increased EV availability

As discussed in Section 9.2.1.1, to extract the maximum benefit of V2G in peak load shaving and avail the corresponding incentives, it has been assumed that an additional 25% of the EV owners connect their vehicle to the charging point during evening peak hours of 6 PM to 9 PM. The increased availability curve has already been shown in Figure 9:3.

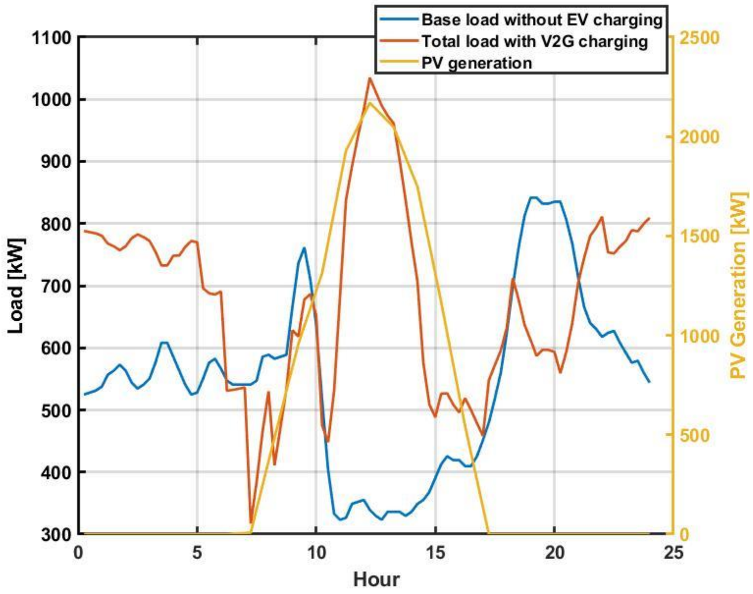

Figure 9:32 Load Curve with increased EV availability at evening peak

Figure 9:32 shows the load curve for such increased availability. As more vehicles are available to reduce the peak demand during this time, we achieve more economical benefits. Using TOD tariff, the annual operating cost is determined for this increased availabilty and is compared with base V2G case. The result, presented in Figure 9:33, clearly show that increasing the availability has sucessfully lowered the operating cost of the system. The savings due to increased EV availability compared to base V2G case is shown in Figure 9:34.

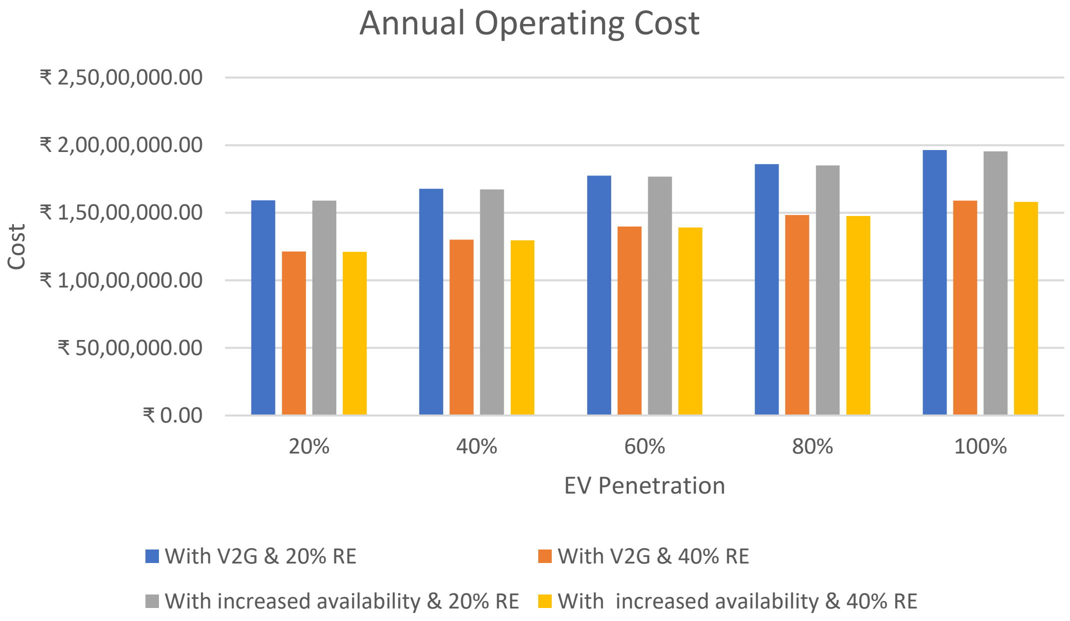

Figure 9:33: Annual operating cost with increased EV availability at evening peak

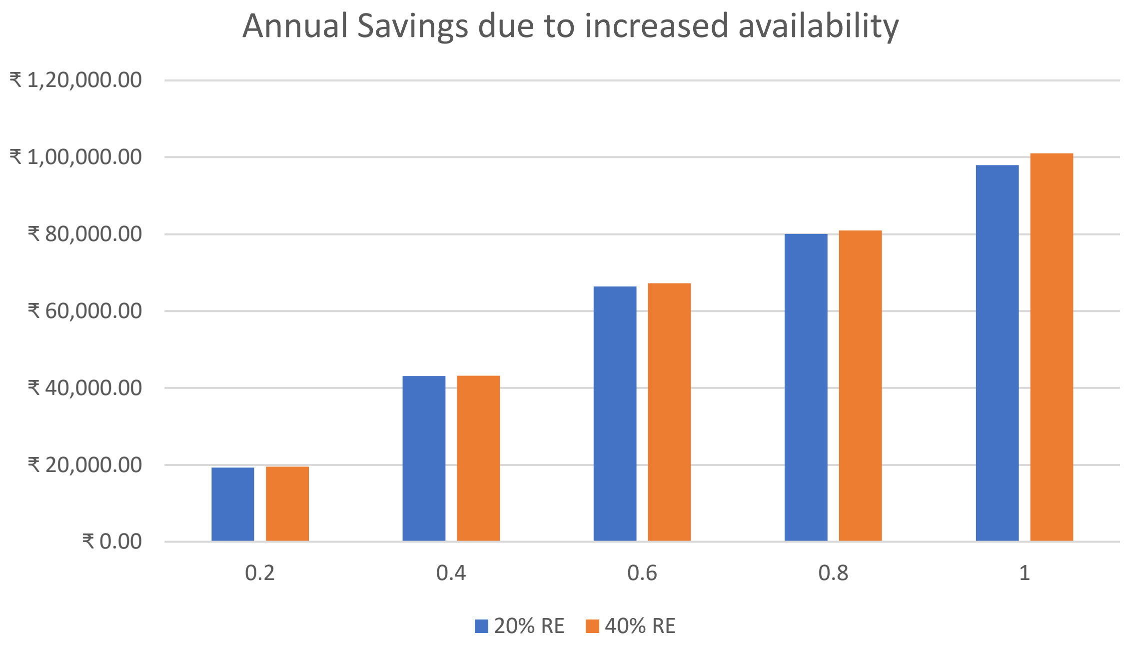

Figure 9:34 Annual savings due to increased EV availability at evening peak

9.8 EV integration for increased RE integration in the Indian Grid

Based on IEA's projection, the total number of EVs and the total energy needed for EV charging are provided in Table 9.2. The annual capacity utilisation factors (CUF) of solar PV plants in India is around 20%[105] and that of wind power plants is around 35%[106] as of 2021. Based on these CUFs, the capacity of RE plants needed to power the EVs in India in 2021, 2025 and 2030 under different scenarios have been provided in Table 9.3, Table 9.4, and Table 9.5 respectively.

Table 9.2: Projected number of EVs and the total energy required for EV charging in India[107]

	2021	2025	2030
EV numbers	23,416.00	6,31,065.00	82,13,440.00
EV energy needed [GWh]	52.4	1503	18938

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[105] Armin Rosencranz, Kamakshi Puri 'Why Increasing India's Solar Energy Capacity Won't Work', The Wire, March 2017. [online] available: https://thewire.in/energy/solar-energy-india-capacity

[106] Prabir Kumar Dash, 'Offshore Wind Energy in India', Ministry of New and Renewable Energy India, April 2019. [online] available: https://mnre.gov.in/img/documents/uploads/2e423892727a456e93a684f38d8622f7.pdf

[107] IEA 'Global EV Outlook 2022'

Table 9.3: Capacity of RE needed (GW) to provide energy to EVs in 2021 under different scenarios.

Solar and Wind combinations	**Energy provided by Renewable energy (%)**				
	100	**80**	**60**	**40**	**20**
100% PV	0.030	0.024	0.018	0.012	0.006
80% PV- 20% Wind	0.027	0.022	0.016	0.011	0.005
60% PV – 40% Wind	0.025	0.020	0.015	0.010	0.005
40% PV – 60% Wind	0.022	0.018	0.013	0.009	0.004
20% PV – 80% Wind	0.020	0.016	0.012	0.008	0.004
0 % Solar – 100 % Wind	0.017	0.014	0.010	0.007	0.003

Table 9.4: Capacity of RE needed (GW) to provide energy to EVs in 2025 under different scenarios.

Solar and Wind combinations	**Energy provided by Renewable energy (%)**				
	100	**80**	**60**	**40**	**20**
100% PV	0.858	0.686	0.515	0.343	0.172
80% PV- 20% Wind	0.784	0.627	0.471	0.314	0.157
60% PV – 40% Wind	0.711	0.569	0.426	0.284	0.142
40% PV – 60% Wind	0.637	0.510	0.382	0.255	0.127
20% PV – 80% Wind	0.564	0.451	0.338	0.225	0.113
0 % Solar – 100 % Wind	0.490	0.392	0.294	0.196	0.098

Table 9.5: Capacity of RE needed (GW) to provide energy to EVs in 2030 under different scenarios.

Solar and Wind combinations	**Energy provided by Renewable energy (%)**				
	100	**80**	**60**	**40**	**20**
100% PV	10.809	8.647	6.486	4.324	2.162
80% PV- 20% Wind	9.883	7.906	5.930	3.953	1.977
60% PV – 40% Wind	8.956	7.165	5.374	3.583	1.791
40% PV – 60% Wind	8.030	6.424	4.818	3.212	1.606
20% PV – 80% Wind	7.103	5.683	4.262	2.841	1.421
0 % Solar – 100 % Wind	6.177	4.941	3.706	2.471	1.235

Further, with V2X, the battery in an EV can be used as a storage unit that can help integrate more RE into the system. As of August 2022, the capacity of solar and wind installations in India is around 57.7 GW and 40.8 GW respectively.[108] Based on the CUF, the average daily energy generation from these solar and wind power plants can be estimated to be around 619.68 GWh. Also, in India, as of August 2022, there are roughly 3.78 crore 4W vehicles109. Considering 10 different scenarios of EV penetration from 2% to 20% with step size of 2%, the number of EVs and the available aggregate storage capacity have been given in Table 9.6. Further, four different cases are considered based on the extent of storage each EV has made available for usage for V2G purposes, as shown in Table 9.7.

Table 9.6: EV penetration scenarios

EV penetration	Total EV numbers	Battery Storage (GWh)
2%	7,56,127.08	30.25
4%	15,12,254.16	60.49
6%	22,68,381.24	90.74
8%	30,24,508.32	120.98
10%	37,80,635.40	151.23
12%	45,36,762.48	181.47
14%	52,92,889.56	211.72
16%	60,49,016.64	241.96
18%	68,05,143.72	272.21
20%	75,61,270.80	302.45

Table 9.7: Cases considered.

Case ID	Storage allowed for V2G (%)
Case 1	10%
Case 2	20%
Case 3	30%
Case 4	40%

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[108] CEA. 'All India Installed Capacity (In MW) Of Power Stations'. https://cea.nic.in/wp-content/uploads/installed/2022/06/IC_June_2022.pdf

[109] Vahansewa, "Dashboard," Ministry of Road Transport & Highways, 2021, [online] available: https://vahan.parivahan.gov.in/vahan4dashboard/vahan/view/reportview.xhtml

Considering the different penetration scenarios and the different cases the aggregate available storage for providing V2G services and the percentage of daily RE generation that can be stored in the EVs have been provided in Table 9.8. For example, from the table at 10% EV penetration, with each EV allowing 20% of its battery storage to be used for V2G services, an aggregate capacity of 30.25 GWh of storage is available which can be utilised to store around 4.88% of the daily energy generated from the cumulative solar and wind power plants in India. Or in other words, a reduction of 5% in RE curtailment can be achieved with 10% EV penetration and each EV providing 20% of its storage for V2G services.

Table 9.8: Amount of RE that can potentially be absorbed by EV batteries.

EV penetration	Available storage (GWh)				% of RE generation stored in EV			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
2%	3.02	6.05	9.07	12.1	0.49	0.98	1.46	1.95
4%	6.05	12.1	18.15	24.2	0.98	1.95	2.93	3.9
6%	9.07	18.15	27.22	36.29	1.46	2.93	4.39	5.86
8%	12.1	24.2	36.29	48.39	1.95	3.9	5.86	7.81
10%	15.12	30.25	45.37	60.49	2.44	4.88	7.32	9.76
12%	18.15	36.29	54.44	72.59	2.93	5.86	8.79	11.71
14%	21.17	42.34	63.51	84.69	3.42	6.83	10.25	13.67
16%	24.2	48.39	72.59	96.78	3.9	7.81	11.71	15.62
18%	27.22	54.44	81.66	108.8	4.39	8.79	13.18	17.57
20%	30.25	60.49	90.74	120.98	4.88	9.76	14.64	19.52

In order to meet the national target of 450 GW of RE by 2030, it has been estimated that a storage capacity of 98 GWh would be needed[110], which can be achieved by electrifying around 16%-20% of the existing 4W stock in India.

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[110] IESA, 'Energy Storage Vision 2030 for India', 2022

9.9 Conclusion

A detailed model of EV charging behaviour was generated in section 9.2. It was observed that for residential charging, EVs were available from late night to morning, while for commercial charging, vehicles were available in the daytime. Using this information, charging of EVs was scheduled in such a way that it avoids charging during morning and evening peak loads. This reduces the peak demand and, hence, less stress on the distribution network and lower charging costs if the TOD tariff is implemented. Various objectives can be achieved by using suitable algorithms for optimum scheduling of EV. For example, in Section 9.3.1, load levelling has been achieved by charging the available vehicles at a higher rate during valley periods and discharging those vehicles during peak demand hours. Similarly, for maximum utilization of RE resources, the available EVs are charged at the maximum rate during the period of RE generation.

It was observed that V2G was more effective in achieving these objectives due to its ability to supply power to the grid during peak load hours. Also, because of this ability, the operating cost of the system is less in V2G compared to the V1G method of charging EVs. These benefits increase with an increase in the penetration of EVs. V2G suffers the disadvantage of the higher capital cost of chargers. Due to this V2G seems to be an economically less feasible option in this study. However, one must note that V2G chargers will be able to provide several other ancillary services to the grid. This will result in increased revenue, making V2G chargers much more effective in future.

Chapter 10. Vehicle to Home and Vehicle to Building

10.1 Introduction

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 loads etc., thereby utilizing the underlying storage more effectively, efficiently, and economically.

10.2 Vehicle to Home (V2H)

Vehicle-to-home or V2H refers to the bidirectional power exchange between the household electric load and the EV. The EV battery can be used to power household appliances during the peak pricing period, and EV can be charged during the off-peak pricing period. EV batteries can also be discharged during peak pricing to earn revenue. The battery should be charged to its desired SoC at the time of plugging out. This section describes and analyses the V2H application of EVs.

10.2.1 Methodology

The EVs have been modelled as described in Section 6.3, while the EV charging scheduling is formulated as an optimisation problem with the objective of minimizing the total electricity cost/bill of the house. Three cases are studied in this section –

- 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

10.2.1.1 Case 1 – V2H with only grid supply

EV charging problem is formulated with the objective of minimisation of the energy cost of the house. The objective of the optimisation is given in Eq. 21.

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} \tag{Eq. 21}$$

where, $C_{elec,t}$ is the cost of electricity in interval t, $P_{grid,t}$ is the power drawn from the main grid in interval t, Δt is the time step for optimisation and $C_{chg,an}$ is the annual levelized cost of bidirectional V2G charger. The constraints for optimisation include power balance constraints are given by Eq. 22; SoC limits constraints are given by Eq. 23, energy constraints for energy to be added are given by Eq. 24, and the maximum allowable charging power (decided by the charger rating) is given by Eq. 25.

$$P_{grid,t} - P_{EV,t} - P_{L,t} = 0 \tag{Eq. 22}$$

$$0.2 \leq SoC_t \leq 0.9 \tag{Eq. 23}$$

$$E_{bat,min} \leq \sum_{t=t_{plug-in}}^{t=t_{plug-out}} \left(P_{ch,t}\eta - \frac{P_{dch,t}}{\eta}\right)t \leq E_{bat,max} \tag{Eq. 24}$$

$$0 \leq \left|P_{EV,t}\right| \leq P_{chg} \tag{Eq. 25}$$

where, $P_{EV,t}$ is the power drawn/injected by the EV charger in interval t, $P_{L,t}$ is the load in interval t, $P_{ch,t}$ is the power drawn by the EV charger in interval t, $P_{dch,t}$ is the power injected by the EV charger during interval t, η is the charger efficiency, $E_{bat,min}$ is the minimum amount of energy that must be added to the EV battery before plugging out, $E_{bat,max}$ is the maximum amount of energy that can be added to the EV battery before plugging out, and P_{chg} is the power rating of the charger. $E_{bat,min}$ and $E_{bat,max}$ are calculated based on the lower limits and upper limits of SoC at the time of plugging out.

10.2.1.2 Case 2 – V2H with grid supply and rooftop solar PV

In this study, three sub-cases are analysed to examine the economic viability of each scenario. In the first case for V2H, a single household with only grid supply is considered, and its optimisation problem along with constraints is formulated as given in Eq. 21 - Eq. 25. It is assumed that the EV model owned by the occupant has a battery pack of 40 kWh and the charger is rated at 7 kW. In the second scenario, the same house with a rooftop solar PV installation is considered. The rating of the rooftop solar PV system is assumed to be 1.5 kWp. The optimisation problem and constraints are modified to include the rooftop solar PV and are given in Eq. 26 and Eq. 27. The rest of the constraints remain the same in Eq. 23, Eq. 24 and Eq. 25.

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} + C_{PV,an} \qquad \text{Eq. 26}$$

$$P_{grid,t} + P_{PV,t} - P_{EV,t} - P_{L,t} = 0 \qquad \text{Eq. 27}$$

where, $C_{PV,an}$ is the annual levelized cost of the rooftop solar PV system and $P_{PV,t}$ is the power generated by the rooftop solar PV system during time interval t.

10.2.1.3 Case 3 – V2H with grid supply, rooftop solar PV and battery storage

In the third case, stationary battery storage with a capacity of 20 kWh is introduced in the system, along with a rooftop solar PV system. The optimisation objective is modified accordingly along with the constraints and is given in Eq. 28 and Eq. 29.

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} + C_{PV,an} + C_{bat,an} \qquad \text{Eq. 28}$$

$$P_{grid,t} + P_{PV,t} - P_{EV,t} - P_{L,t} - P_{bat,t} = 0 \qquad \text{Eq. 29}$$

where, $C_{bat,an}$ is the annual levelized cost of the stationary battery storage system and $P_{bat,t}$ is the power drawn/injected by the stationary battery storage system during time interval t.

The electricity tariff structure considered in this study is shown in Figure 10:1. 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[111]. The daily load profile of a single house considered for this study is shown in Figure 10:2.

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[111] The Maharashtra Time of Day tariff for EV charging have been considered here. To be noted that although this tariff is not yet applicable for residential consumers, it has been assumed to be applicable for residential consumers in this study.

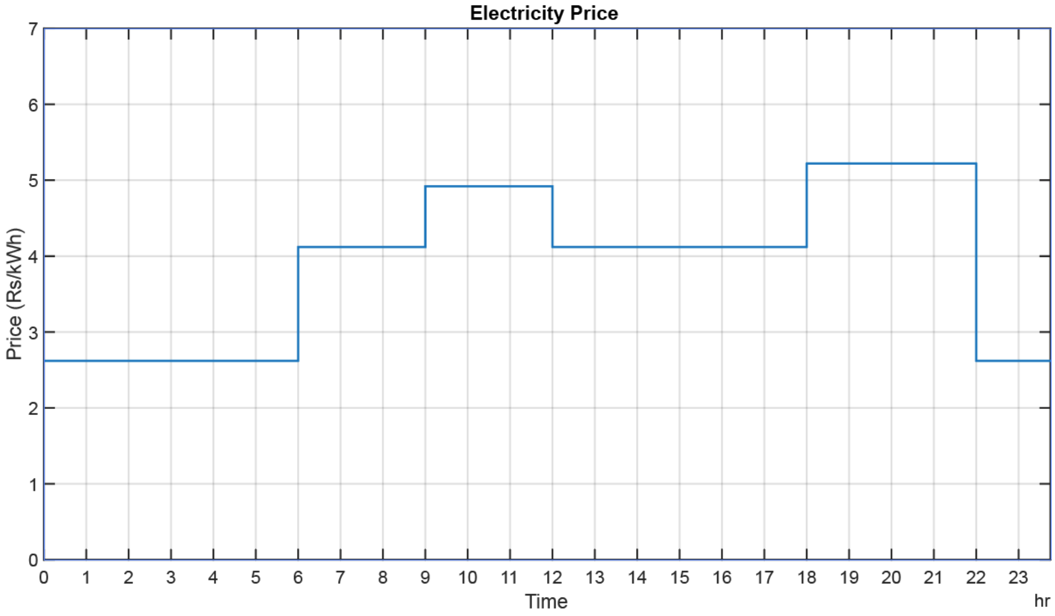

Figure 10:1: Representative tariff structure considered for study[112].

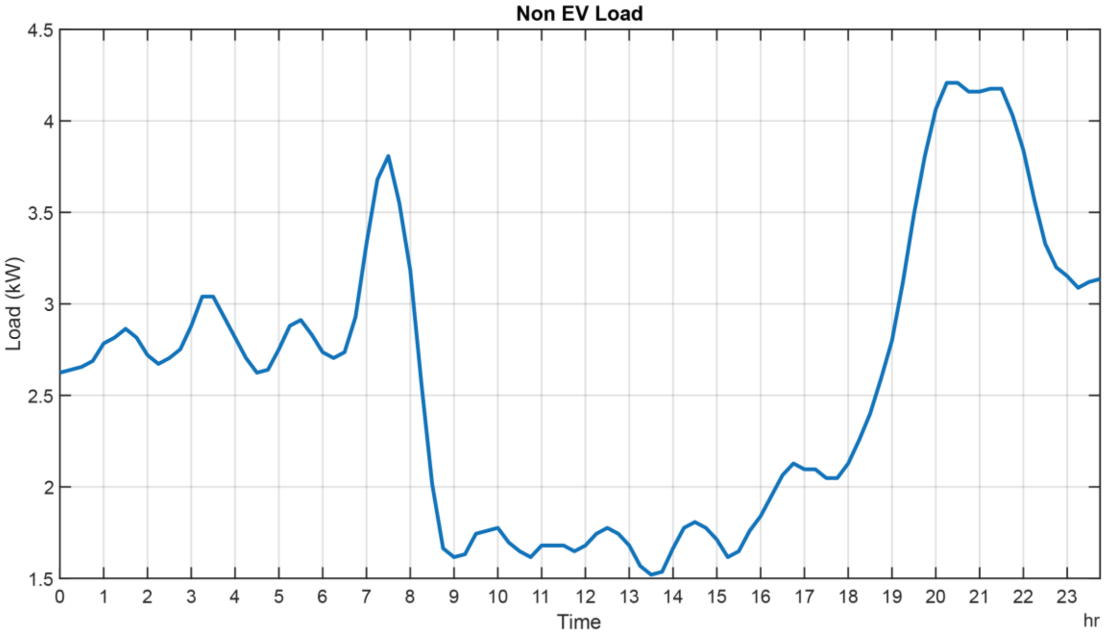

Figure 10:2. Representative non-EV load curve for a single house [113]

The generation curve for the rooftop solar PV plant considered in the study is shown in Figure 10:3. The other relevant parameters considered for this study are provided in Table 10.1.

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[112] Commercial Circular no. 323, Maharashtra State Electricity Distribution Company Limited, April 2020.

[113] T. Qian, K. Wang, Y. Li, X. Guo, and J. Liu, "Analysis of Electric Load Characteristics of Commercial and Public Buildings Based on Big Data," IOP Conference Series: Materials Science and Engineering, vol. 394, no. 4, p. 042105, Jul. 2018, doi: 10.1088/1757-899X/394/4/042105.

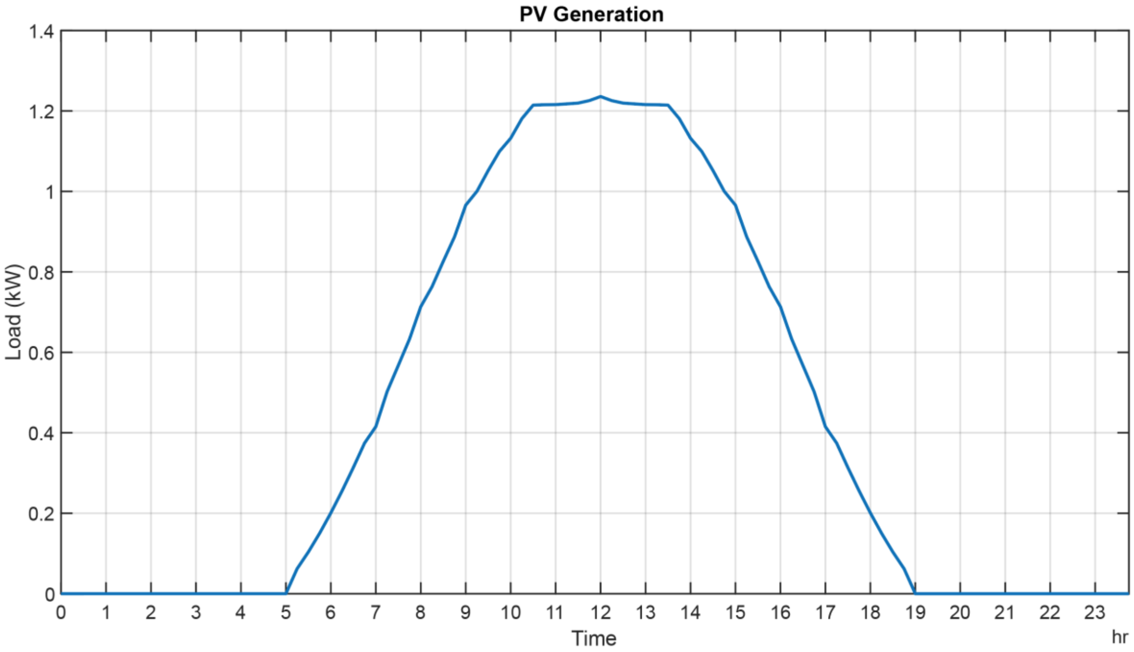

Figure 10:3. Generation from rooftop solar PV.

Table 10.1. Parameters considered.

Electrical Parameters	Value
Plugin SoC	0.36
Plug out SoC min	0.8
Plug out SoC max	0.85
Size of EV Battery (kWh)	40
Charger Rating (kW)	7
Minimum SoC	0.1
Maximum SoC	0.95
Charger efficiency (%)	90[114]
Size of stationary battery storage (kWh)	8.7
Battery power rating (kW)	5.5
Plugin time	19:00
Plug-out time	08:00 (the following day)
Time step (Δt) (in min)	15
Cost Parameters	**Value**
Discount Rate (%)	10
Life of rooftop solar PV system (years)	20
Life of stationary battery storage system (years)	8
Capital Investment	**Value**
Capital cost of stationary battery storage system (INR/kWh)	60000 (EUR 704.06)
Capital cost of rooftop solar PV system (INR/kWp)	55000[115] (EUR 645.39)

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[114] Chen et al., "Strategic integration of vehicle-to-home system with home distributed photovoltaic power generation in Shanghai," Applied Energy, vol. 263, Apr. 2020, doi: 10.1016/j.apenergy.2020.114603

[115] Kenbrooksolar " 2kW Solar System Price and Details for home in India" https://kenbrooksolar.com/system/2kw-solar-system-price

10.2.2 Results

From the resultant EV charging curve shown in Figure 10:4, it can be seen that during the peak price hours, the EV is feeding power to the house, thereby reducing energy imports from the grid during this span while charging the EV during periods of low tariff. In this context, negative charging implies reverse power flow from the EV to the house. The overall load curve of the considered house is shown in Figure 10:5, which shows that the net load of the house decreased during the normal pricing and the peak pricing periods. The energy drawn is shifted to the off-peak pricing periods leading to lower cost of electricity consumption for the customer.

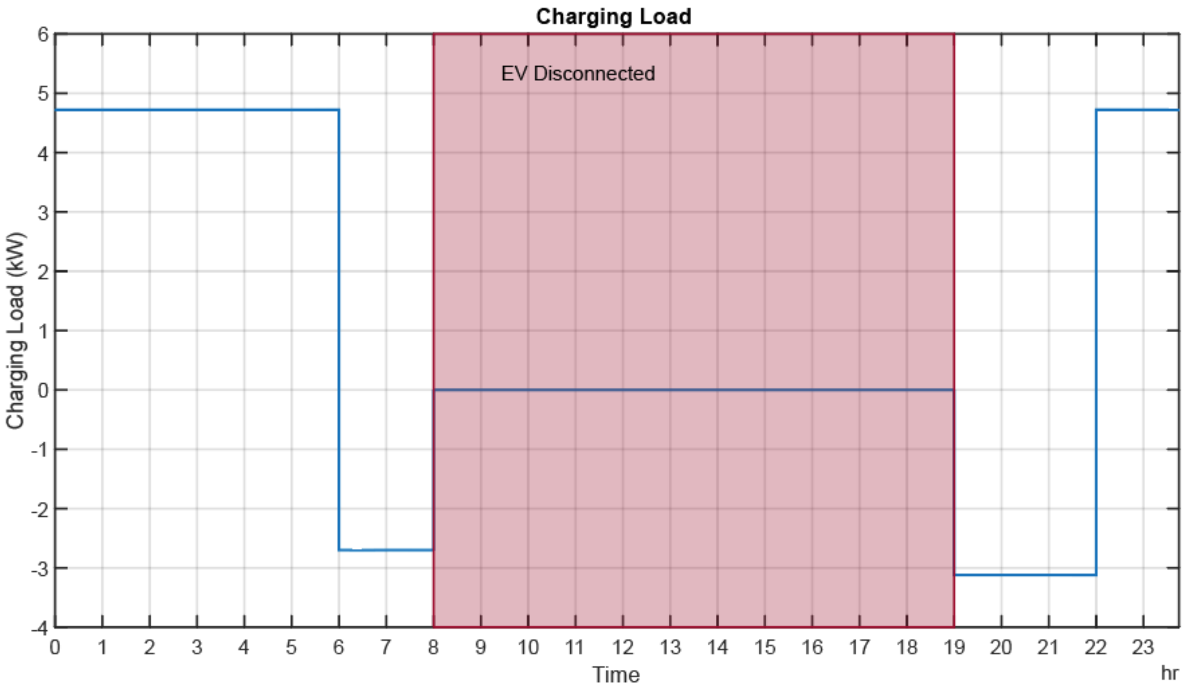

Figure 10:4. EV charging curve for case 1 and case 2[116]*.*

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[116] As the EV is already charged by the time PV generation starts, so the energy generated from PV is not used while charging the EV. So the EV charging curves for both the cases are identical. The energy generated from the PV is used to power the remaining loads in the house, with surplus generation being sold to the grid.

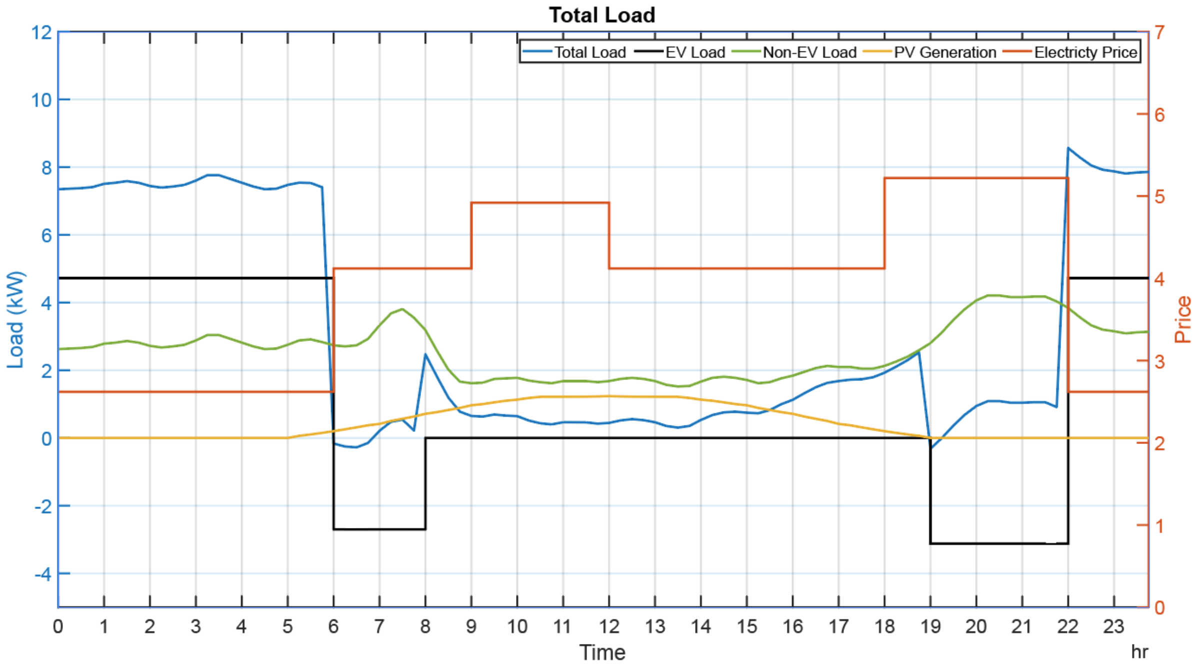

Figure 10:5. Overall load curve of the house for case 2.

With addition of battery storage in Case 3, the net load of the house goes to negative in the evening peak periods, implying that power is fed back to the grid, thus generating revenue as shown in Figure 10:6.

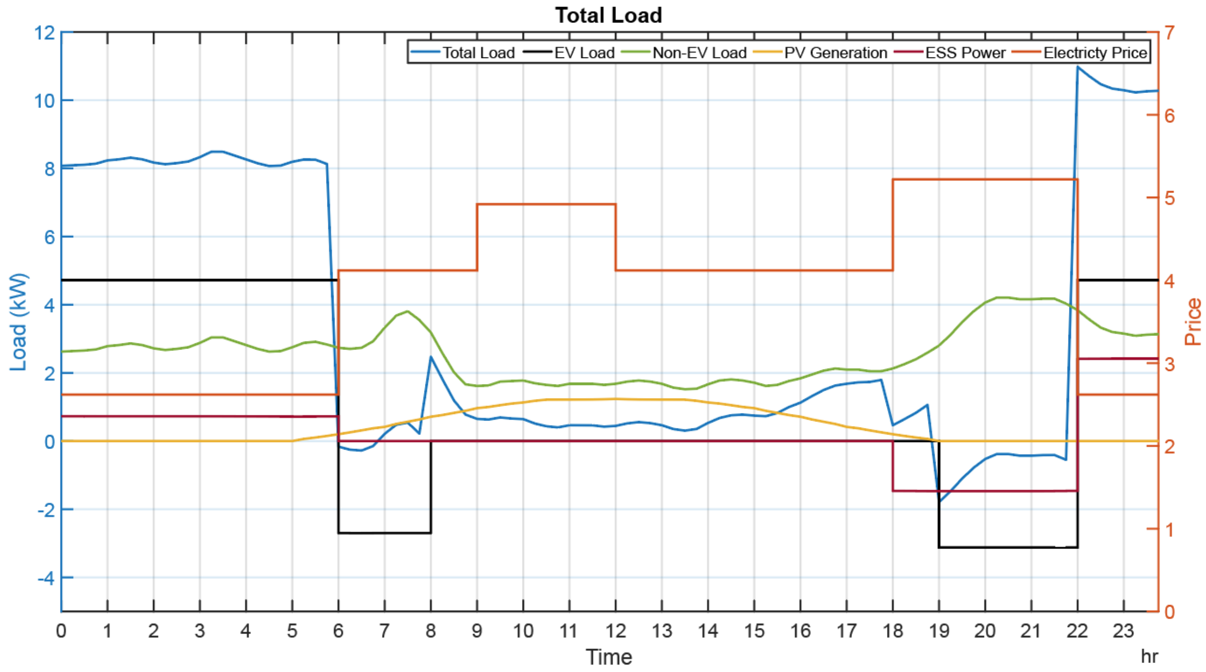

Figure 10:6: Overall load curve of the house for Case 3

The energy cost incurred by the house owner per day for each case is summarized in Table 10.2, and the annual levelized cost for the complete system in all three cases is summarized in Table 10.3.

Table 10.2. Cost incurred per day

Case	Cost incurred per day (in INR/day)
Case 1: Only Grid Supply	267.07 (EUR 3.13)
Case 2: Grid Supply + PV System	220.78 (EUR 2.59)
Case 3: Grid Supply + PV System + Battery Storage	214.18 (EUR 2.51)

Table 10.3. Annual Levelized Cost

Case	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	97480.55 (EUR 1143.87)
Case 2: Grid Supply + PV System	93505.26 (EUR 1097.22)
Case 3: Grid Supply + PV System + Battery Storage	188942.03 (EUR 2217.11)

It can be observed 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 the rooftop solar PV system and the stationary battery storage system. As the battery storage unit added more flexibility, the user was able to significantly reduce the energy drawn from the grid during the peak price periods. This lead to further reduction in the daily energy cost of the user. 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. With the addition of PV in Case 2, the capital expenditure was around INR 1.1 lakh (EUR 1300), however, the capital expenditure in Case 3 is INR 6.32 lakhs (EUR 7,466). So the high capital expenditure of energy storage significantly increases the annualized levelized cost.

10.2.3 Effect of seasonal variations

The above analysis was extended by considering the hourly variation in non-EV loads and EV charging behaviour on a month-wise basis, separately for weekdays and weekends. The non-EV load for different months on weekdays and weekends is shown in Figure 10:7 and Figure 10:8, respectively.

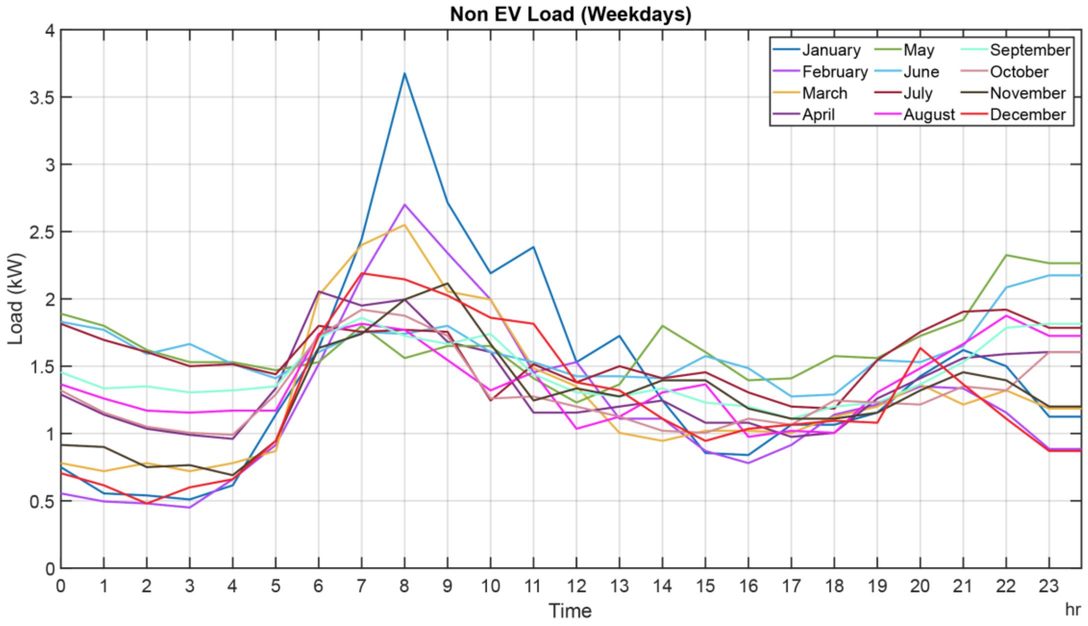

Figure 10:7. Non-EV load on weekdays [117]

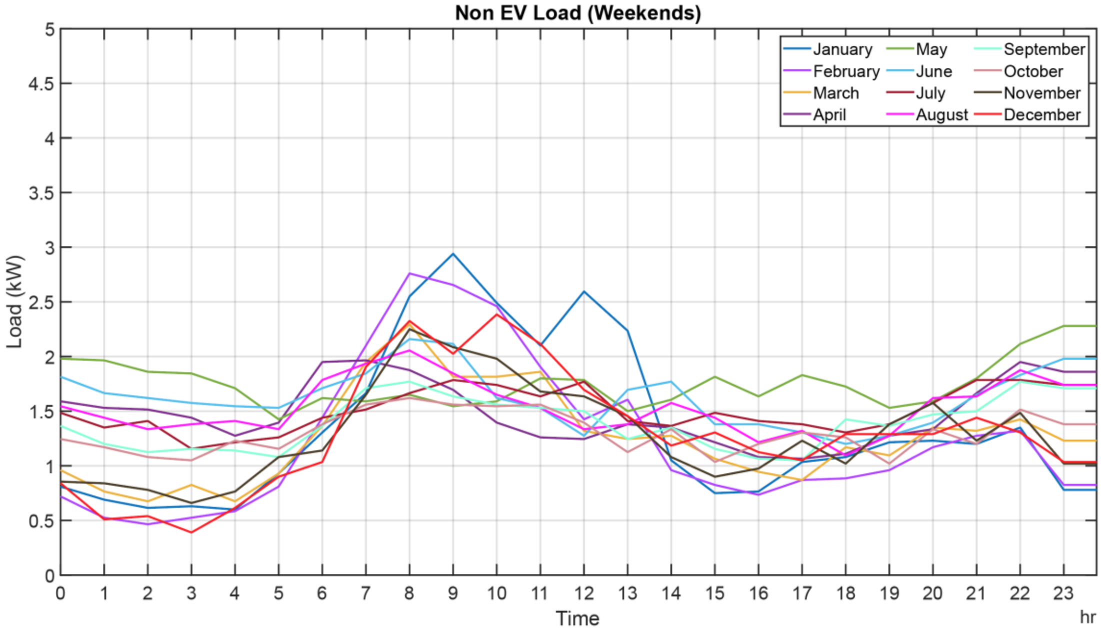

Figure 10:8. Non-EV load on weekends117

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[117] BEE, 'National Energy End-use Monitoring', https://neemdashboard.in/index.php

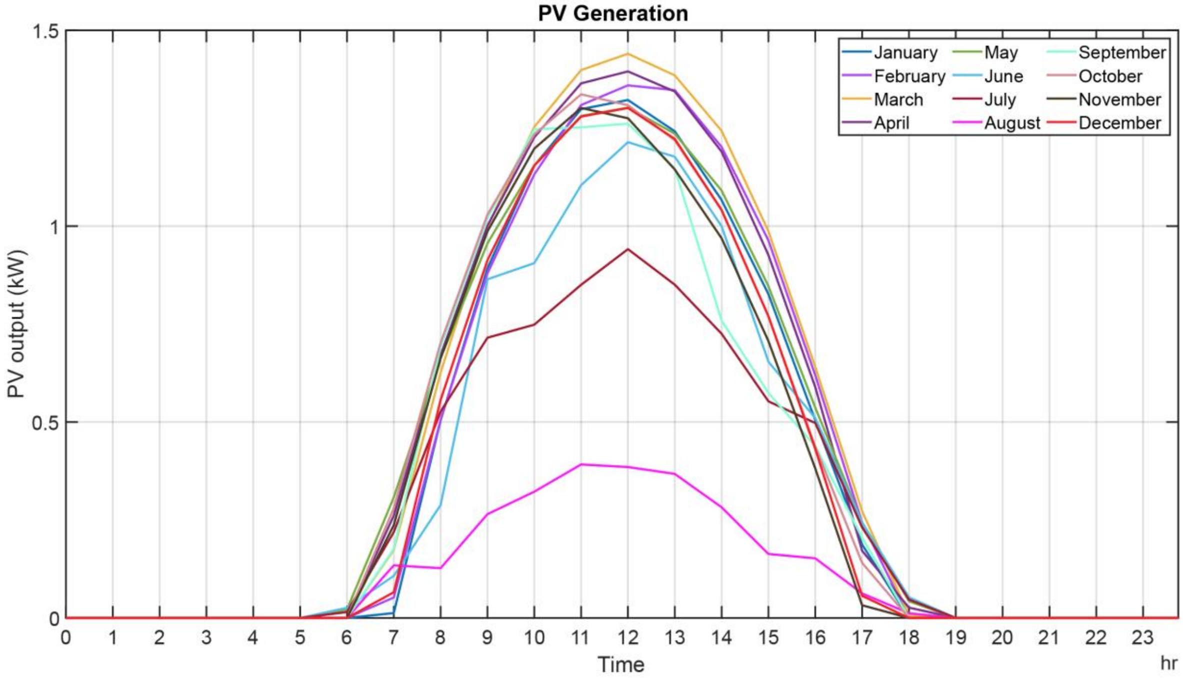

Figure 10:9. Power generated from solar PV in different months[118]

The resultant EV charging curves for Case-3, along with the total load and cost curve, is shown in Figure 10:10 and Figure 10:11, respectively. In this case, a rooftop solar PV with a capacity of 2 kWp and stationary battery storage of 8.7 kWh (with a 5.5 kW converter) is considered.

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[118] NREL, 'PVWatts Calculator', https://pvwatts.nrel.gov/

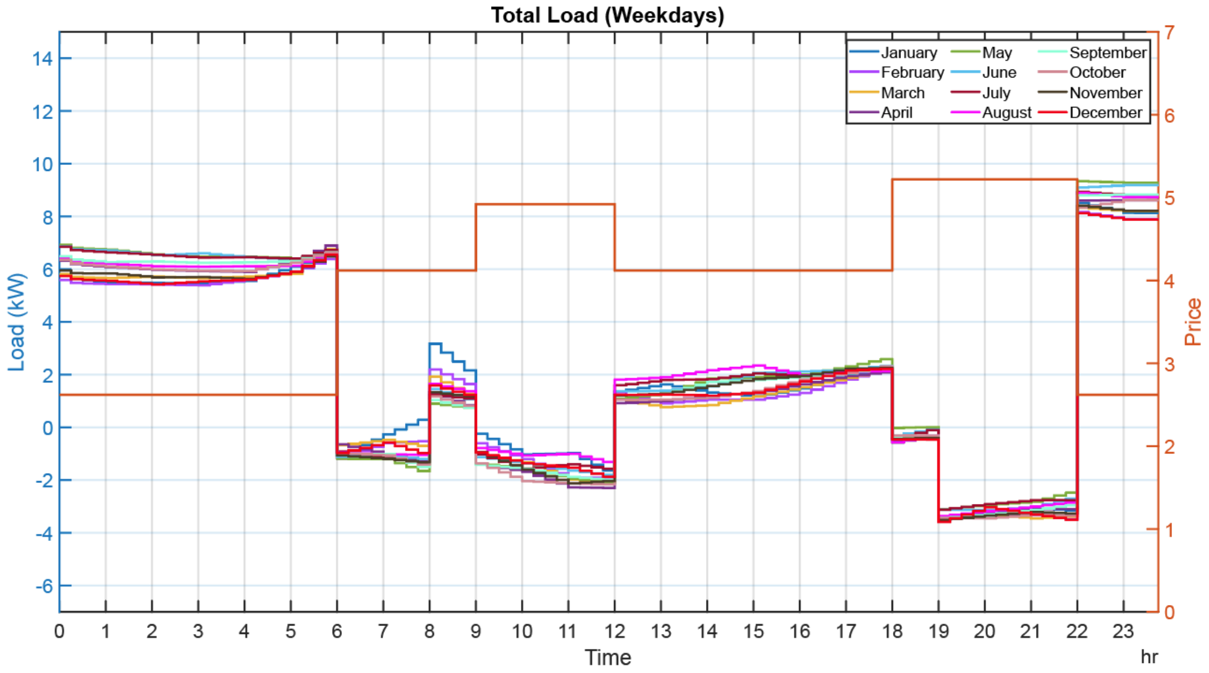

Figure 10:10. Total load of house (including EV charging load) for different months on weekdays for case 3.

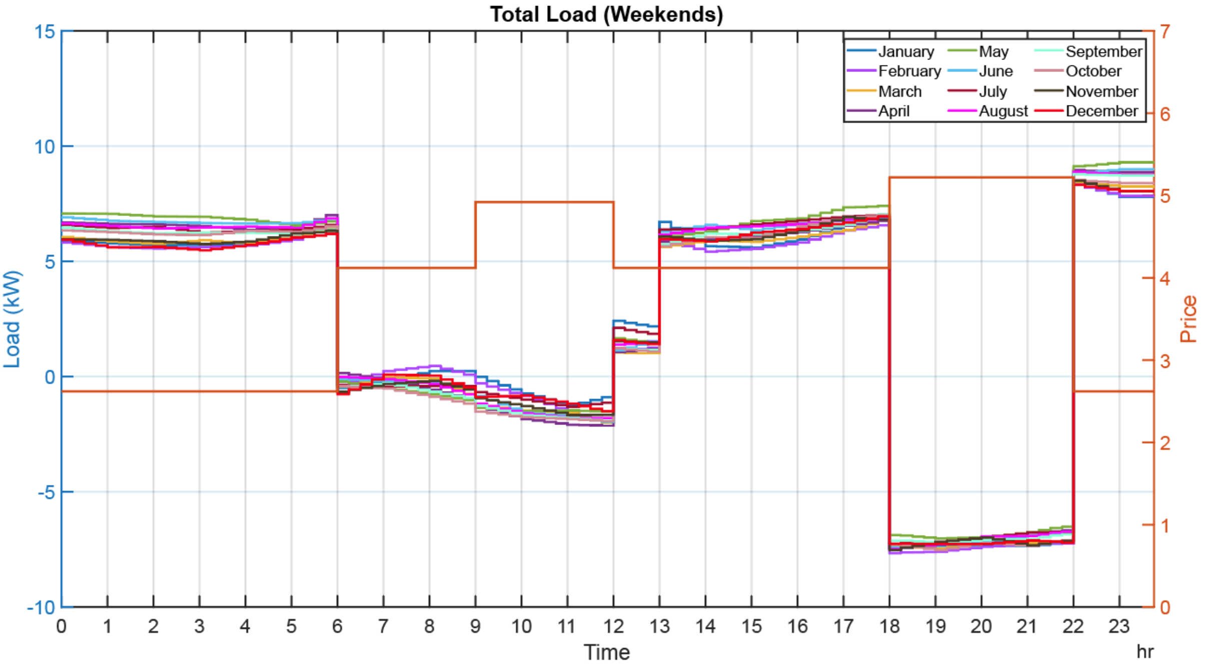

Figure 10:11. Total load of the house (including EV charging load) for different months on weekends for case 3.

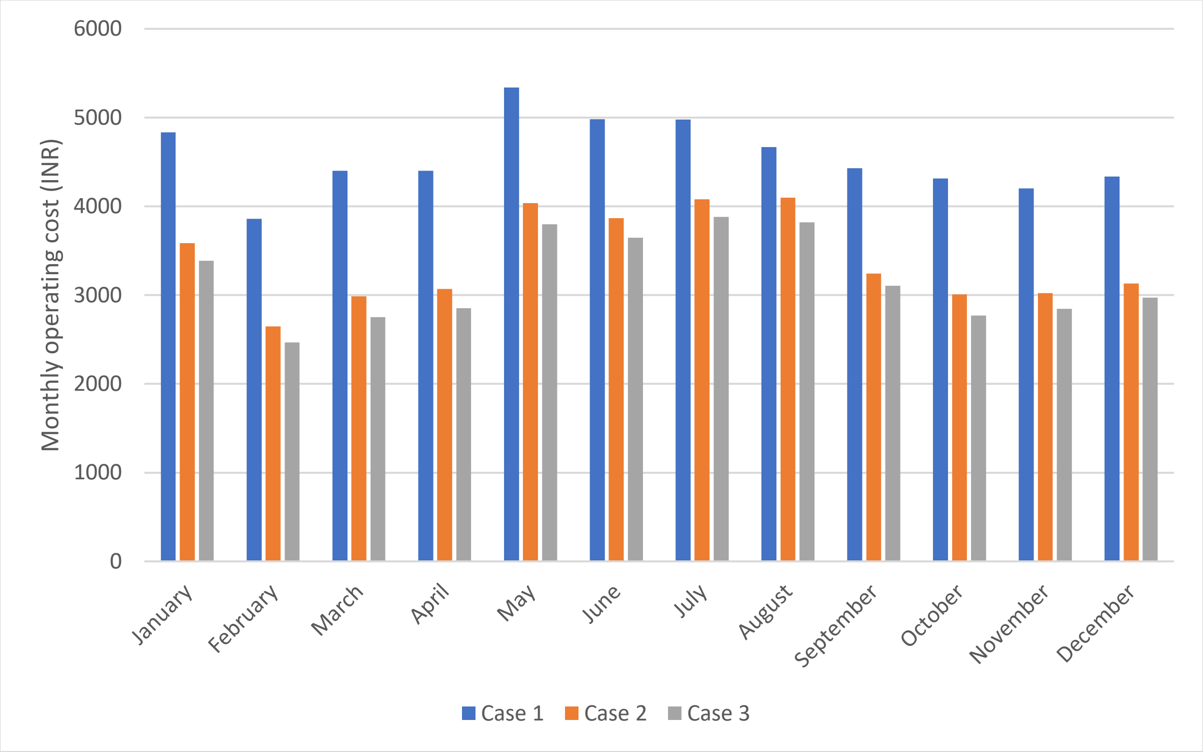

Figure 10:12: Monthwise comparison of operating cost for the three cases

The operating costs and annual levelized costs for all three cases are summarised and compared in Table 10.4 Comparison of three cases in terms of operational and annual levelized costs.

Table 10.4 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)

The total load of the property across seasonal variations is shown in Figure 10:10 and Figure 10:11. From Figure 10:10 it can be observed that the total load of the property is mostly negative during the peak pricing periods implying that energy is fed back to the grid. This is primarily driven by the energy storage unit in the residence. In comparison, during weekends, the load of the property is slightly higher from 1 pm to 6 pm. This is because as during weekends the EVs are assumed to be present in the residence itself, the vehicle charges during this period to discharge during the evening peak periods as shown in Figure 10:11. The variation in monthly operating costs can be seen in Figure 10:12 and it can be observed that the operating costs are high in months when solar PV generation is relatively low.

10.2.4 Optimal Planning of rooftop solar PV and battery storage for V2H

The optimal sizing of rooftop solar PV and battery storage for V2H is achieved by formulating an optimisation problem with the objective function given in Eq. 30.

$$\min\left(\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + S_{PV}C_{PV,an} + S_{bat}C_{bat,an}\right) \qquad \text{Eq. 30}$$

where, S_{PV} is the rating of the rooftop solar PV system, and S_{bat} is the capacity of the battery storage system. So, in effect, the objective of the optimization function is to determine the optimal size of PV and battery storage so that the total annualized cost of the system (including operational cost and capital cost) is minimized. The upper and lower bounds for S_{PV} are taken as 0 kWp and 8 kWp, and for S_{bat} are taken as 10 kWh and 40 kWh. On varying the upper and lower bounds of S_{bat}, it was observed that the optimal solution is always the one with a lower bound of S_{bat}[119]. On the contrary, with the variation in the upper and lower bounds of S_{PV}, it was observed that the optimal solution is always the one with the former. The final load curve with optimal rating of rooftop solar PV system and battery storage system is shown in Figure 10:13.The optimal PV capacity in this scenario is 8 kWp which the upper bound considered, while the optimal battery capacity is 10 kWh,

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[119] The high capital cost of battery storage is currently a prohibiting factor. However, this cost is expected to reduce by 30%-60% by 2030 (NREL, Cost Projections for Utility-Scale Battery Storage: 2021 Update', 2021, https://www.nrel.gov/docs/fy21osti/79236.pdf)

which was the lower bound considered. The annual levelized cost in this scenario was INR 1.7 lakhs (EUR 2,036).

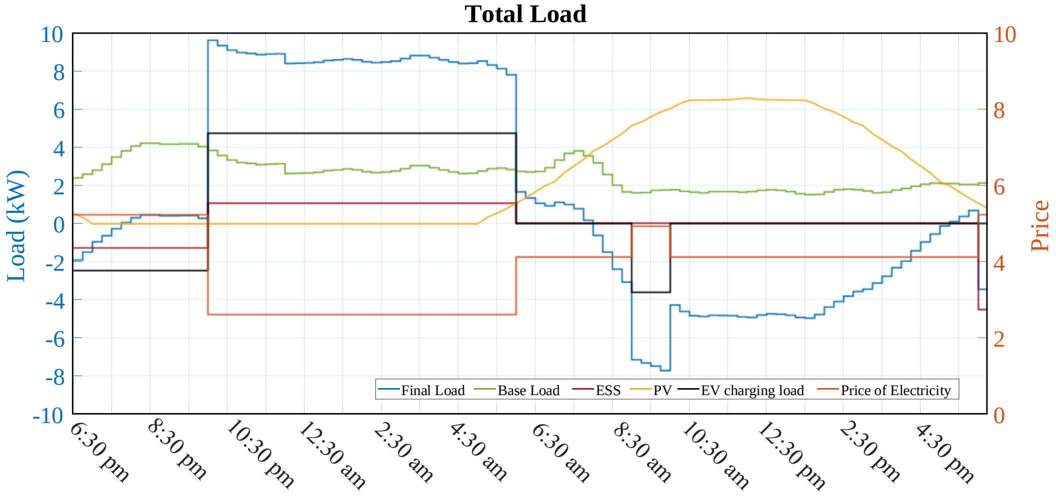

Figure 10:13. Total load with optimal sizing of rooftop solar PV system and battery storage system.

10.2.5 Dimesnional Analysis

For the dimensional analysis of V2H, different parameters are considered included, including two different tariff types, different energy sources as well as dumb charging, smart charging and bidirectional charging. The two tariffs considered are shown in Figure 10:12 Tariff 1 is the actual tariff, based on the ToD tariff of Maharashtra and Tariff2 is the modified tariff, where the price of the peak periods is increased, while the price of off-peak periods is decreased. This is done to increase the incentive for participating in energy shifting for the EV user.

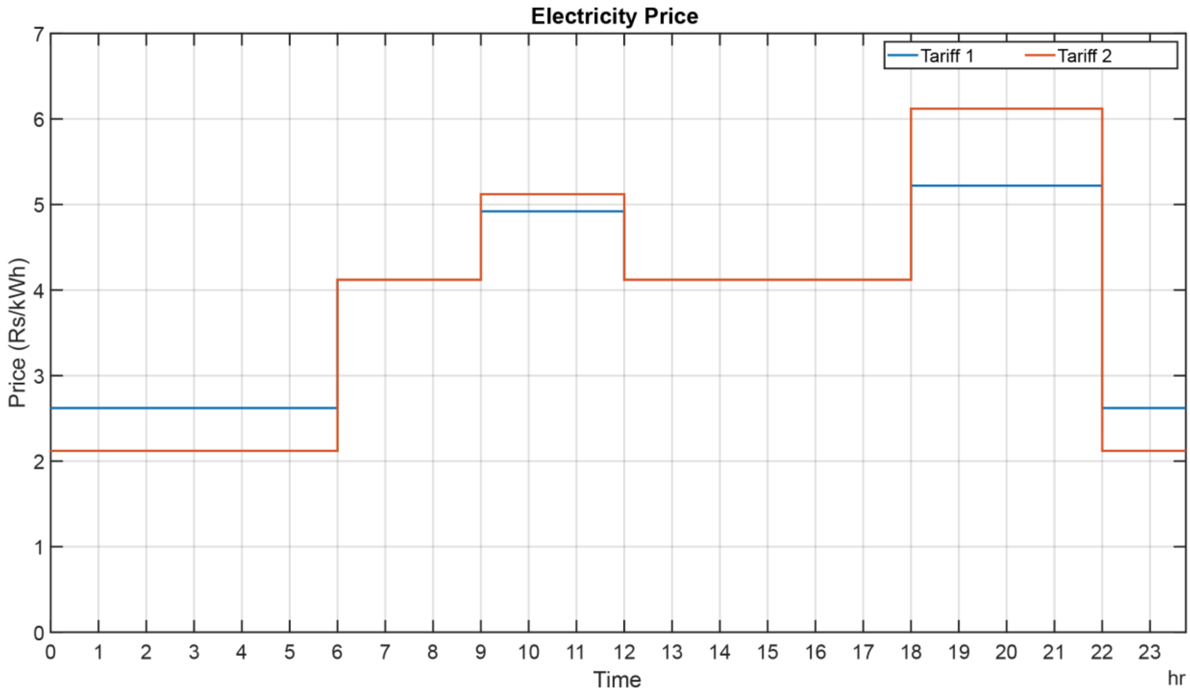

Figure 10:14. The two tariffs taken into consideration. Tariff 1 is the actual tariff, based on the ToD tariff of Maharashtra and Tariff2 is the modified tariff, where the price of the peak periods is slightly increased while price of offpeak periods is slightly dec

The daily operational cost for the EV user is given in Table 10.5 and the annual operating cost is provided in Table 10.6, which shows that the operational cost with V2H is much lower compared to V0G and V1G. Also with tariff 2, the operational cost is even lower.

Table 10.5. Daily operational cost

Operational Cost Per day in INR						
	Normal tariff			**Tariff 2**		
	Only Grid	**Grid + PV**	**Grid + PV+ Battery**	**Only Grid**	**Grid + PV**	**Grid + PV+ Battery**
V2H	₹ 267.07	₹ 220.78	₹ 214.18	₹ 241.66	₹ 194.61	₹ 177.94
V1G	₹ 290.43	₹ 244.15	₹ 237.55	₹ 282.56	₹ 235.51	₹ 218.84
V0G	₹ 362.57	₹ 316.29	₹ 309.69	₹ 380.75	₹ 333.70	₹ 317.03
Operational Cost Per day in EUR						
	Normal tariff			**Tariff 2**		
	Only Grid	**Grid + PV**	**Grid + PV+ Battery**	**Only Grid**	**Grid + PV**	**Grid + PV+ Battery**
V2H	€ 3.13	€ 2.59	€ 2.51	€ 2.84	€ 2.28	€ 2.09
V1G	€ 3.41	€ 2.86	€ 2.79	€ 3.32	€ 2.76	€ 2.57
V0G	€ 4.25	€ 3.71	€ 3.63	€ 4.47	€ 3.92	€ 3.72

Table 10.6: Annual operational cost

Operational Cost Annual in INR						
	Normal tariff			Tariff 2		
	Only Grid	Grid + PV	Grid + PV+ Battery	Only Grid	Grid + PV	Grid + PV+ Battery
V2H	₹ 97,480.55	₹ 80,584.70	₹ 78,175.70	₹ 88,205.90	₹ 71,032.65	₹ 64,948.10
V1G	₹ 1,06,006.95	₹ 89,114.75	₹ 86,705.75	₹ 1,03,134.40	₹ 85,961.15	₹ 79,876.60
V0G	₹ 1,32,338.05	₹ 1,15,445.85	₹ 1,13,036.85	₹ 1,38,973.75	₹ 1,21,800.50	₹ 1,15,715.95
Operational Cost Annual in EUR						
	Normal tariff			Tariff 2		
	Only Grid	Grid + PV	Grid + PV+ Battery	Only Grid	Grid + PV	Grid + PV+ Battery
V2H	€ 1,143.87	€ 945.61	€ 917.34	€ 1,035.04	€ 833.52	€ 762.12
V1G	€ 1,243.92	€ 1,045.70	€ 1,017.43	€ 1,210.21	€ 1,008.70	€ 937.30
V0G	€ 1,552.90	€ 1,354.68	€ 1,326.41	€ 1,630.76	€ 1,429.25	€ 1,357.85

From the operating costs, the annual savings that can be made by switching to V2H or V1G from V0G is estimated as shown in Table 10.7, which shows that the highest savings is made by switching from V0G to V2H. The NPV considering 10 years of operation and at 10% discount rate is given in Table 10.8. One observation that can be made from the annual savings is that, the savings are almost equal across the three energy input scenarios of grid, grid + PV and grid + PV + battery scenarios, even though a decrease in operational cost is seen with the addition of PV and storage as shown in Table 10.6. This can be explained because, the EV is not present in the household during periods of PV generation, so the energy generated from the PV is not being effectively used by the EV. Taking into consideration the cost of EV chargers provided in Table 10.9, the economic viability of investing in V2H or V1G chargers is provided in Table 10.10. From the table it can be observed that comparatively lower capita 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 an economically viable opportunity. With tariff 2 the business case for V1G and V2H chargers become even stronger with a much higher amount of savings earned.

Table 10.7: Annual Savings

Annual Savings in INR						
	Normal tariff			**Tariff 2**		
	Only Grid	**Grid + PV**	**Grid + PV+Battery**	**Only Grid**	**Grid + PV**	**Grid + PV+Battery**
V0G-V1G	₹ 26,329.64	₹ 26,332.56	₹ 26,331.10	₹ 35,838.40	₹ 35,838.99	₹ 35,838.26
V0G-V2H	₹ 34,857.50	₹ 34,861.15	₹ 34,861.15	₹ 50,767.85	₹ 50,767.85	₹ 50,767.85
V1G-V2H	₹ 8,527.86	₹ 8,528.59	₹ 8,530.05	₹ 14,929.45	₹ 14,928.86	₹ 14,929.60
Annual Savings in EUR						
	Normal tariff			**Tariff 2**		
	Only Grid	**Grid + PV**	**Grid + PV+Battery**	**Only Grid**	**Grid + PV**	**Grid + PV+Battery**
V0G-V1G	€ 308.96	€ 309.00	€ 308.98	€ 420.54	€ 420.55	€ 420.54
V0G-V2H	€ 409.03	€ 409.07	€ 409.07	€ 595.73	€ 595.73	€ 595.73
V1G-V2H	€ 100.07	€ 100.08	€ 100.09	€ 175.19	€ 175.18	€ 175.19

Table 10.8: NPV of savings for 10 years

NPV of 10 year savings in INR						
	Normal tariff			**Tariff 2**		
	Only Grid	**Grid + PV**	**Grid + PV+Battery**	**Only Grid**	**Grid + PV**	**Grid + PV+Battery**
V0G-V1G	₹ 1,61,784.24	₹ 1,61,802.18	₹ 1,61,793.21	₹ 2,20,211.46	₹ 2,20,215.05	₹ 2,20,210.56
V0G-V2H	₹ 2,14,184.25	₹ 2,14,206.68	₹ 2,14,206.68	₹ 3,11,946.46	₹ 3,11,946.46	₹ 3,11,946.46
V1G-V2H	₹ 52,400.01	₹ 52,404.49	₹ 52,413.46	₹ 91,735.00	₹ 91,731.41	₹ 91,735.90
NPV of 10 year savings in EUR						

	Normal tariff			Tariff 2		
	Only Grid	Grid + PV	Grid + PV+Battery	Only Grid	Grid + PV	Grid + PV+Battery
V0G-V1G	€ 1,898.43	€ 1,898.64	€ 1,898.54	€ 2,584.03	€ 2,584.08	€ 2,584.02
V0G-V2H	€ 2,513.31	€ 2,513.57	€ 2,513.57	€ 3,660.48	€ 3,660.48	€ 3,660.48
V1G-V2H	€ 614.88	€ 614.93	€ 615.04	€ 1,076.45	€ 1,076.41	€ 1,076.46

Table 10.9: Cost of 7 kW charger with different capabilities

Cost in INR			
	V0G	V1G	V2G
Capital Cost (INR)	₹ 40,000.00	₹ 60,000.00	₹ 2,82,000.00
Cost in EUR			
	V0G	V1G	V2G
Capital Cost (INR)	€ 469.37	€ 704.06	€ 3,309.08

Table 10.10: Difference between increment in capital expenditure and NPV of savings considering 10 years of operational lifetime

Cost in INR						
	Normal tariff			Tariff 2		
	Only Grid	Grid + PV	Grid + PV+Battery	Only Grid	Grid + PV	Grid + PV+Battery
V0G-V1G	₹ 1,73,788	₹ 1,73,810	₹ 1,73,799	₹ 2,43,774	₹ 2,43,778	₹ 2,43,773
V0G-V2H	₹ 14,554	₹ 14,581	₹ 14,581	₹ 1,31,656	₹ 1,31,656	₹ 1,31,656
V1G-V2H	₹ -1,59,234	₹ -1,59,229	₹ -1,59,218	₹ -1,12,118	₹ -1,12,122	₹ -1,12,117
Cost in EUR						
	Normal tariff			Tariff 2		
	Only Grid	Grid + PV	Grid + PV+Battery	Only Grid	Grid + PV	Grid + PV+Battery

V0G-V1G	€ 2,039	€ 2,040	€ 2,039	€ 2,861	€ 2,861	€ 2,861
V0G-V2H	€ 171	€ 171	€ 171	€ 1,545	€ 1,545	€ 1,545
V1G-V2H	€ -1,869	€ -1,868	€ -1,868	€ -1,316	€ -1,316	€ -1,316

10.3 Vehicle-to-Building

Vehicle-to-building or V2B refers to the bidirectional power exchange between a building's electric load and the EV fleet. The batteries of EVs can be used to power the building loads during the peak pricing period and can be charged during the off-peak pricing period. EV batteries can also be discharged during peak pricing to earn revenue. The batteries should be charged to their desired SoC when plugging out. 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.

10.3.1 Methodology

The EV charging scheduling is formulated as an optimisation problem with the objective of minimising of total electricity cost of the building. Three cases are studied in this section –

- 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

EV charging problem is formulated with the objective of minimisation of the energy cost of the building. The objective of the optimisation is given in Eq. 31,

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} \qquad \text{Eq. 31}$$

where, $C_{elec,t}$ is the cost of electricity in interval t, $P_{grid,t}$ is the power drawn from the main grid in interval t, Δt is the time step for optimisation and $C_{chg,an}$ is the annual levelized cost of bidirectional V2G charger. The constraints for optimisation include power balance constraints given by Eq. 32, SoC limits constraints given by Eq. 33, energy constraints for energy to be added given by Eq. 34, and the maximum allowable charging power (decided by the charger rating) given by Eq. 35,

$$P_{grid,t} - \left(\sum_{i=1}^{N} P_{EV,i,t}\right) - P_{L,t} = 0 \qquad \text{Eq. 32}$$

$$0.2 \le SoC_{i,t} \le 0.9 \quad \forall i \in \{1,2,3 \dots N\} \qquad \text{Eq. 33}$$

$$E_{bat_i,min} \le \sum_{t=t_{plug-in}}^{t=t_{plug-out}} \left(P_{ch_i,t}\eta - \frac{P_{dch_i,t}}{\eta}\right) t \le E_{bat_i,max} \quad \forall i \in \{1,2,3 \dots N\} \qquad \text{Eq. 34}$$

$$0 \le \left|P_{EV_i,t}\right| \le P_{chg} \quad \forall i \in \{1,2,3 \dots N\} \qquad \text{Eq. 35}$$

where, $P_{EV,i,t}$ is the power drawn/injected by the i^{th} EV charger in interval t, $P_{L,t}$ is the load in interval t, $P_{ch,i,t}$ is the power drawn by the i^{th} EV charger in interval t, $P_{dch,i,t}$ is the power injected by the i^{th} EV charger during interval t, η is the charger efficiency, $E_{bat,i,min}$ is the minimum amount of energy that must be added to the battery of i^{th} EV before plugging out, $E_{bat,i,max}$ is the maximum amount of energy that can be added to the battery of i^{th} EV before plugging out and P_{chg} is the power rating of the charger. $E_{bat,i,min}$ and $E_{bat,i,max}$ are calculated based on the lower limits and upper limits of SoC at the time of plugging out.

In this study, three cases are analysed to examine the economic viability of each case. In the first case for V2B, a single commercial office building with only grid supply is considered, and its optimisation problem along with constraints is formulated by Eq. 31 – Eq. 35. It is assumed that the EVs owned by the office employees get charged at the building premises during the day. The battery capacities of these EVs are generated using a normal distribution with a mean of 40 kWh and a standard deviation of 5 kWh.

In the second case, the same commercial office building with a rooftop solar PV installation is considered. The rating of the rooftop solar PV system is assumed to be 25 kWp initially, and the effect of change in the rating of rooftop solar PV is also studied. The optimisation problem and constraints are modified to include the rooftop solar PV and are given in Eq. 36 and Eq. 37. The rest of the constraints remain the same as equations Eq. 33, Eq. 34 and Eq. 35.

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} + C_{PV,an} \qquad \text{Eq. 36}$$

$$P_{grid,t} + P_{PV,t} - \left(\sum_{i=1}^{N} P_{EV,i,t}\right) - P_{L,t} = 0 \qquad \text{Eq. 37}$$

where, $C_{PV,an}$ is the annual levelized cost of the rooftop solar PV system and $P_{PV,t}$ is the power generated by the rooftop solar PV system during time interval *t*.

In the third case, stationary battery storage with a capacity of 125 kWh is introduced in the system along with a rooftop solar PV system. Accordingly, the optimisation objective is modified along with the constraints and is given in equations Eq. 38 and Eq. 39.

$$\min\left(\sum_{t=1}^{t=T} C_{elec,t}P_{grid,t}\Delta t\right) + C_{chg,an} + C_{PV,an} + C_{bat,an} \qquad \text{Eq. 38}$$

$$P_{grid,t} + P_{PV,t} - \left(\sum_{i=1}^{N} P_{EV,i,t}\right) - P_{L,t} - P_{bat,t} = 0 \qquad \text{Eq. 39}$$

where, $C_{bat,an}$ is the annual levelized cost of the stationary battery storage system and $P_{bat,t}$ is the power drawn/injected by the stationary battery storage system during time interval *t*.

The representative electricity tariff structure considered in this study is shown in Figure 10:15. The base price of INR 14.33/kWh is taken with a surcharge of INR 1.1 /kWh during peak hours and a rebate of INR 1.5/kWh during off-peak hours for a commercial load. For EV charging load, a separate tariff structure is considered with a base price of INR 5.5 /kWh taken with a surcharge of INR 1.1 /kWh during peak hours and a rebate of INR 1.5 /kWh during off-peak hours. The representative load profile of a commercial office building considered for this study is shown in Figure 10:16. The battery capacities of EVs are assumed based on the Gaussian normal distribution with a mean battery capacity of 40 kWh and a standard deviation of 5 kWh. The battery capacities are illustrated in Figure 10:17. The SoC of EVs at the time of plugin is assumed to follow a Gaussian normal distribution with a mean SoC of 0.3 and a standard deviation of 0.1. The initial SoC of EVs is shown in Figure 10:18. The availability of EVs in the building based on the arrival time and departure time of EVs is shown in

Figure 10:19. The parameters considered for this study are given in

Table 10.11.

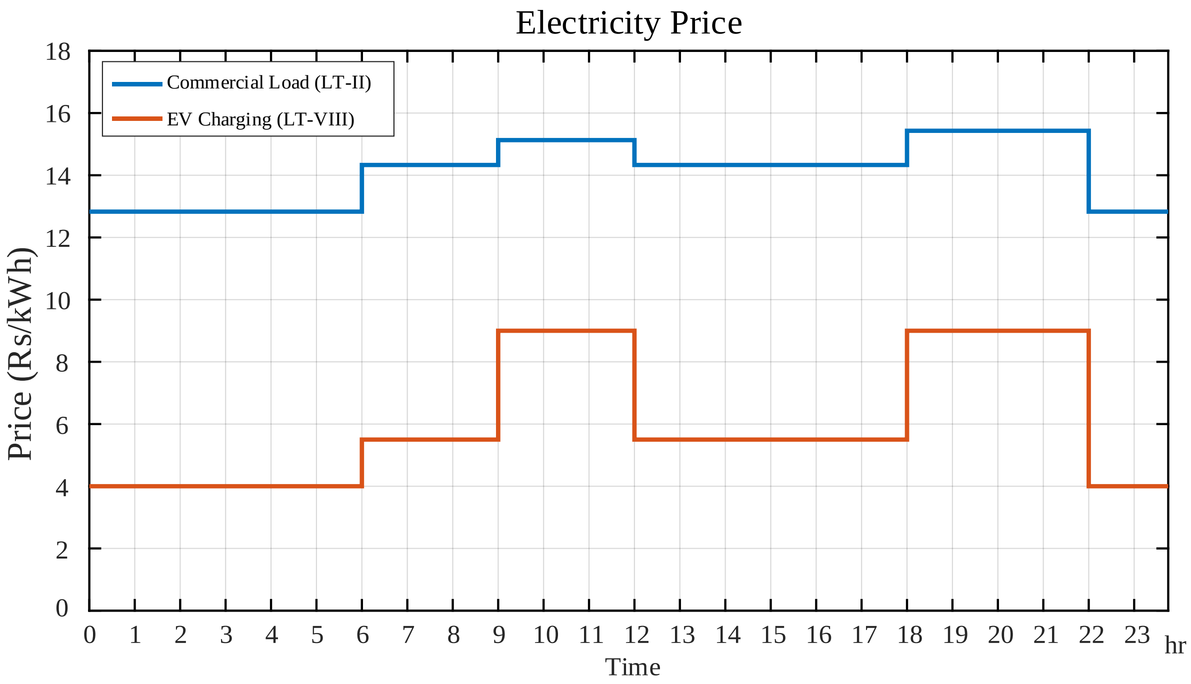

Figure 10:15. Tariff structure for commercial load and EV load.

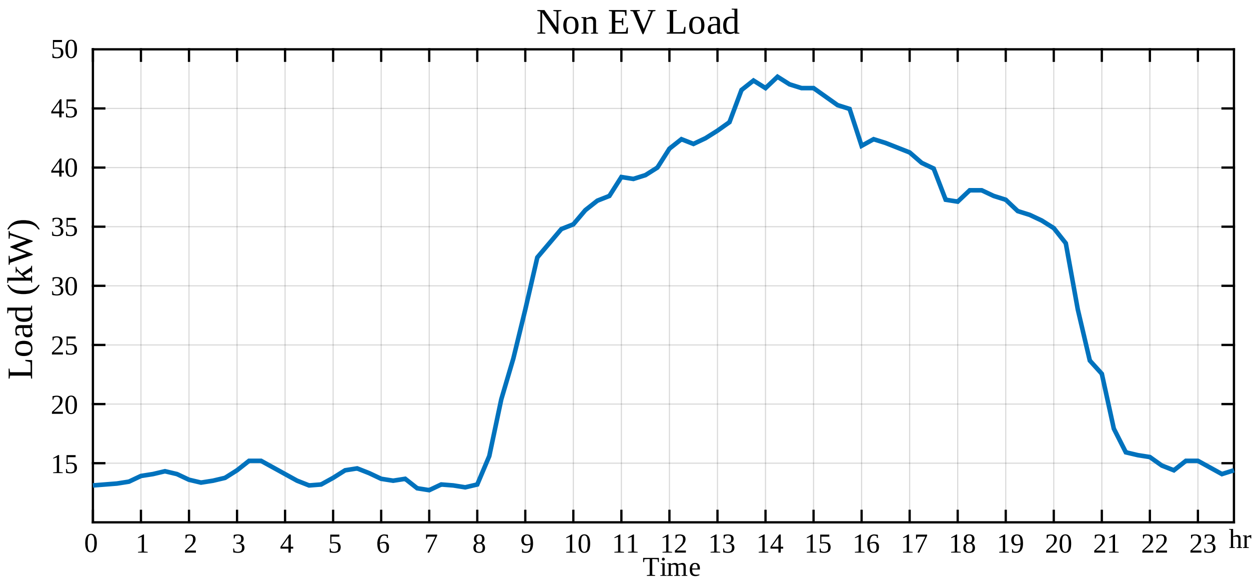

Figure 10:16. Representative non EV load curve for a commercial office building [120].

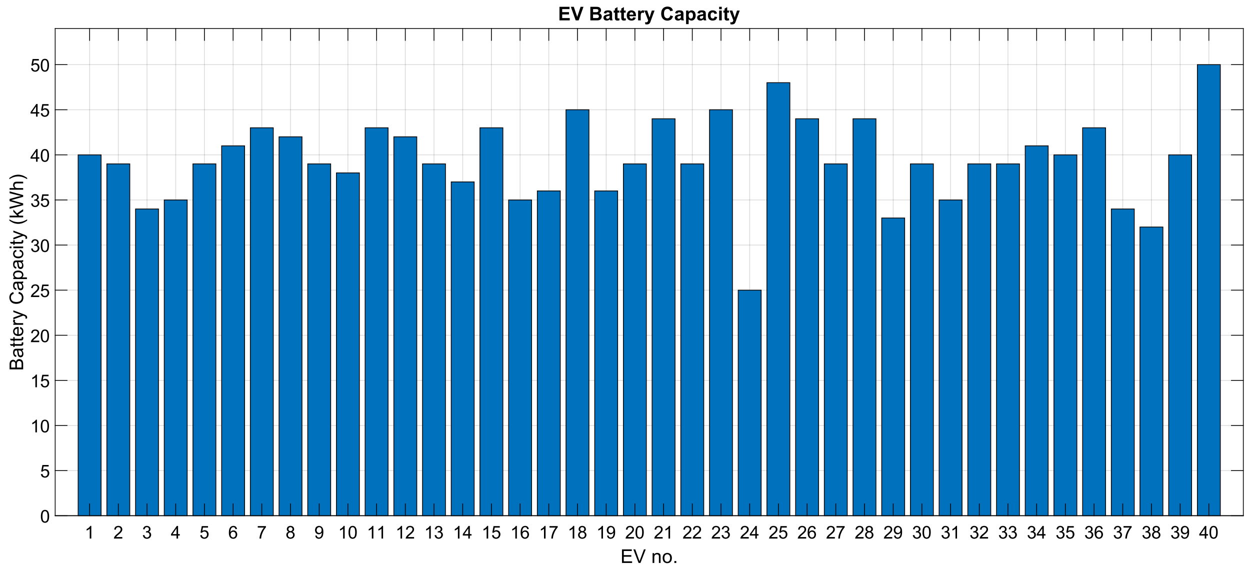

Figure 10:17. Battery capacity of each EV.

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[120] T. Qian, K. Wang, Y. Li, X. Guo, and J. Liu, "Analysis of Electric Load Characteristics of Commercial and Public Buildings Based on Big Data," IOP Conference Series: Materials Science and Engineering, vol. 394, no. 4, p. 042105, Jul. 2018, doi: 10.1088/1757-899X/394/4/042105.

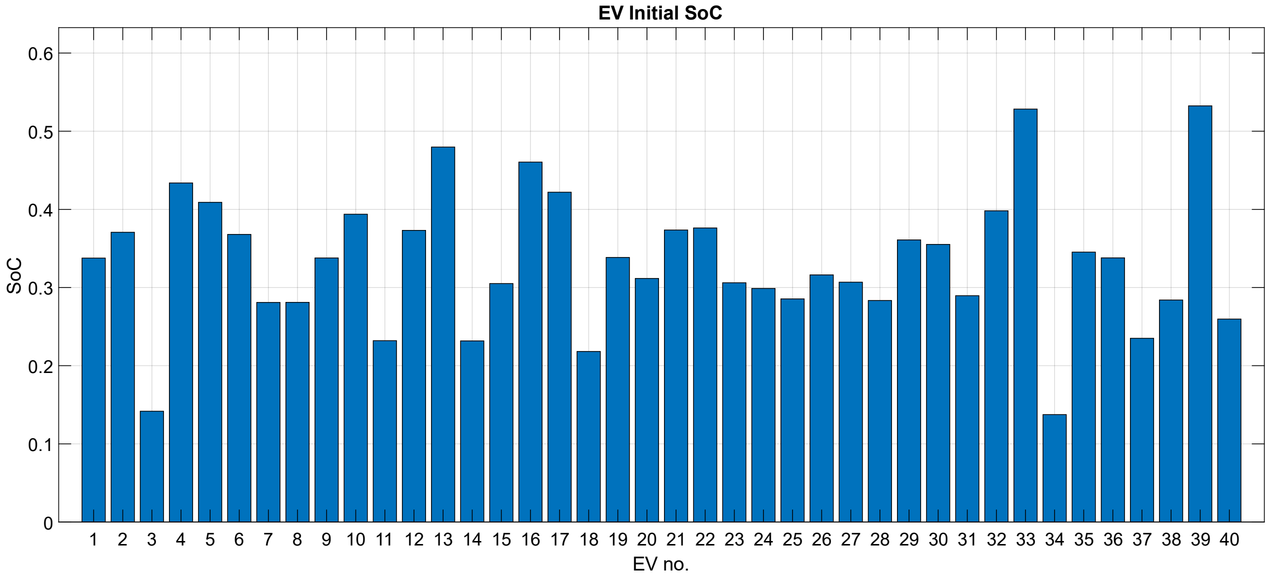

Figure 10:18. Initial SoC of each EV.

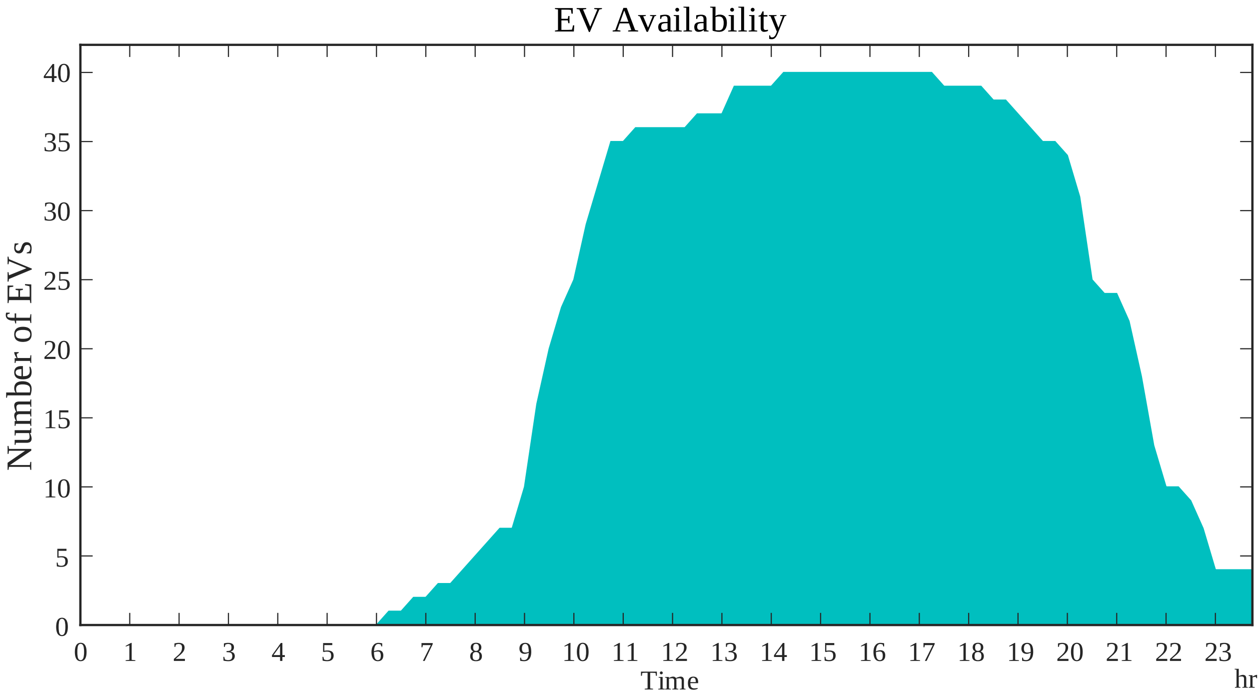

Figure 10:19. EV availability at the building for over a day[121].

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[121] Thomas, D., Deblecker, O., & Ioakimidis, C. S. (2018). Optimal operation of an energy management system for a grid-connected smart building considering photovoltaics' uncertainty and stochastic electric vehicles' driving schedule. Applied Energy, 210, 1188–1206.

Table 10.11. Parameters considered

Electrical Parameters	**Value**
Plug out SoC	(0.8-0.9)
Charger Rating (kW)	22
Minimum SoC	0.1
Maximum SoC	0.95
Charger Efficiency (%)	90
Size of Stationary Battery Storage (kWh)	125
Time step (Δ*t*) (in min)	15
Cost Parameters	Value
Discount Rate (%)	10
Life of rooftop Solar PV system (years)	20
Life of stationary battery storage system (years)	8
Capital Investment	Value
Capital Cost of stationary battery storage system (INR/kWh)	60000 (EUR 704.06)
Capital Cost of rooftop solar PV system (INR/kWp)	55000 (EUR 645.39)
Cost of unidirectional 22 kW charger (V0G) (in INR)	90,000[122,123] (EUR 1056.09)
Cost of unidirectional 22 kW charger (V1G) (in INR)	1,35,000122,123 (EUR 1584.18)
Cost of bidirectional 22 kW charger (V2G) (in INR)	6,34,500122,123 (EUR 7445.44)

10.3.2 Results

After solving the optimisation problem, the resultant EV charging curves along with non-EV load, PV generation and the final load for Case 3 are shown in Figure 10:20. The SoC of EVs during the entire day is shown in Figure 10:21.

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[122] Michael Nicholas, "Estimating Electric Vehicle Charging Infrastructure Costs across Major U.S. Metropolitan Areas" (ICCT, August 2019)

[123] Huber, D., De Clerck, Q. De Cauwer, C., Sapountzoglou, N.Coosemans, T., Messagie, M. 'Vehicle to Grid Impacts on the Total Cost of Ownership for Electric Vehicle Drivers'. World Electr. Veh. J. 2021, 12, 236.

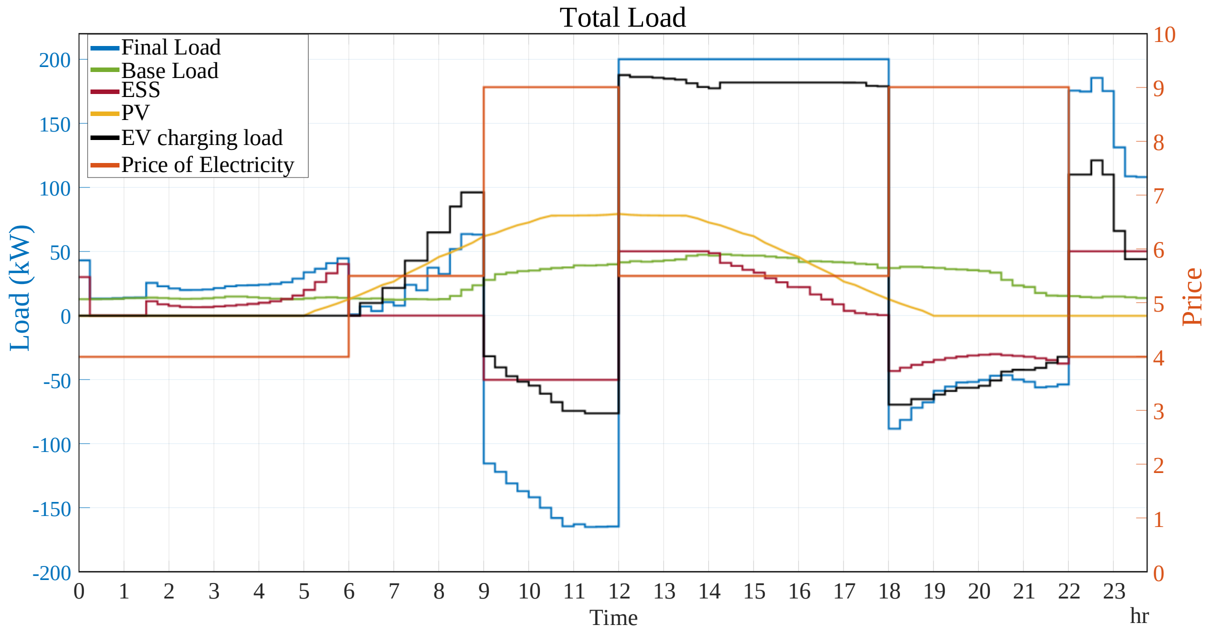

Figure 10:20. Total load of the building over a day for case 3.

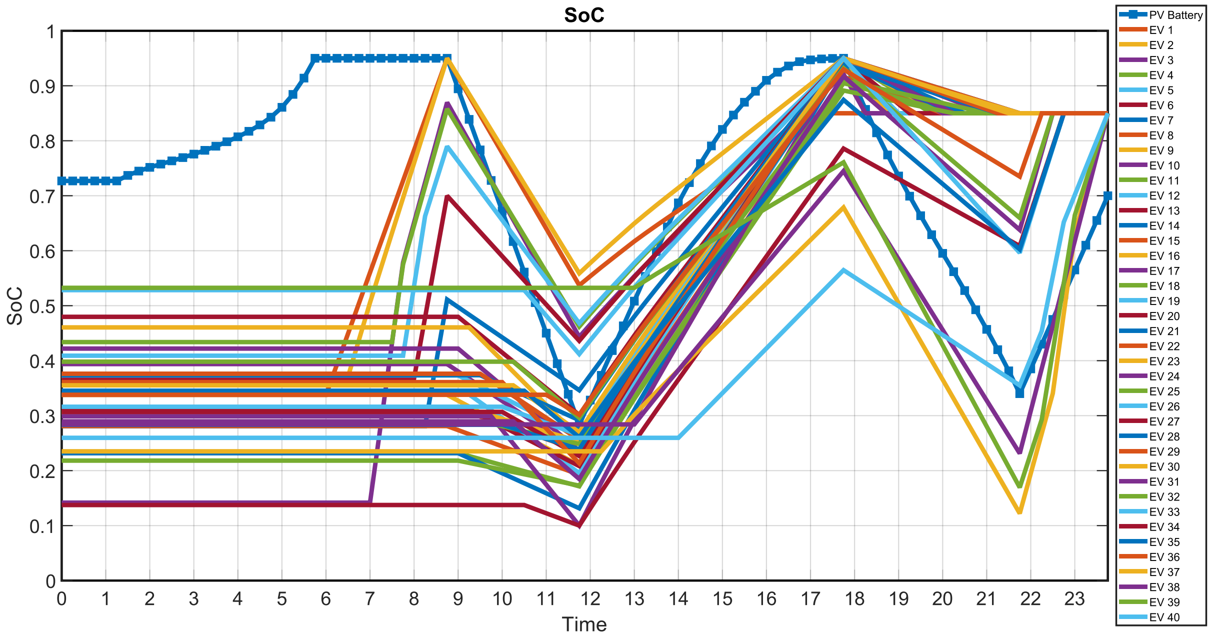

Figure 10:21. SoC of EVs and stationary battery for case 3.

The operating cost for case 1 is shown in Figure 10:22. It can be observed that the operating cost per day is significantly higher for the dumb charging (V0G) case. The operating cost in unidirectional smart charging (V1G) is relatively less than the V0G case but is higher than the bidirectional smart charging (V2G) case. The annual levelized cost per EV, as shown in Figure 10:23, is higher for the V2G case compared to the V1G case and the V0G case when a fleet of 40 EVs is considered. This can be rationalized based on the high cost of bidirectional chargers. For lower number of EVs, the savings made by switching to V2G was enough to offset the capital expenditure, which made the total annual levelized cost to be almost similar. But, with 40 EVs, the effective utilization of resources was reduced compared to lower number of EVs because of the maximum contracted power limit of the building. This meant that the total potential of the V2B resource was not fully utilized when 40 EVs were considered. So, the initial capital expenditure was unable to be made up with the lowered savings and so the annual levelized cost was higher for this scenario.

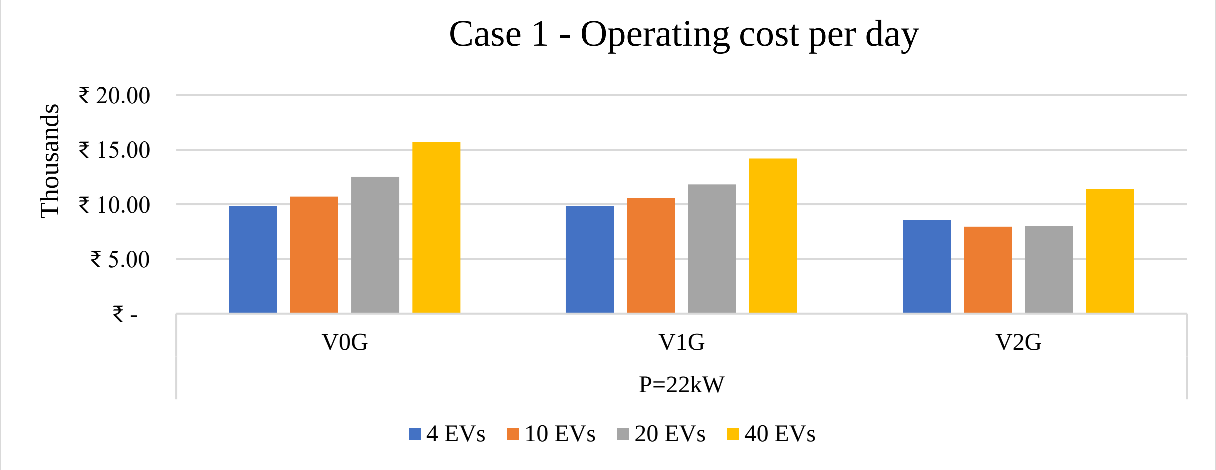

Figure 10:22. Operating cost per day for case 1 – only grid supply

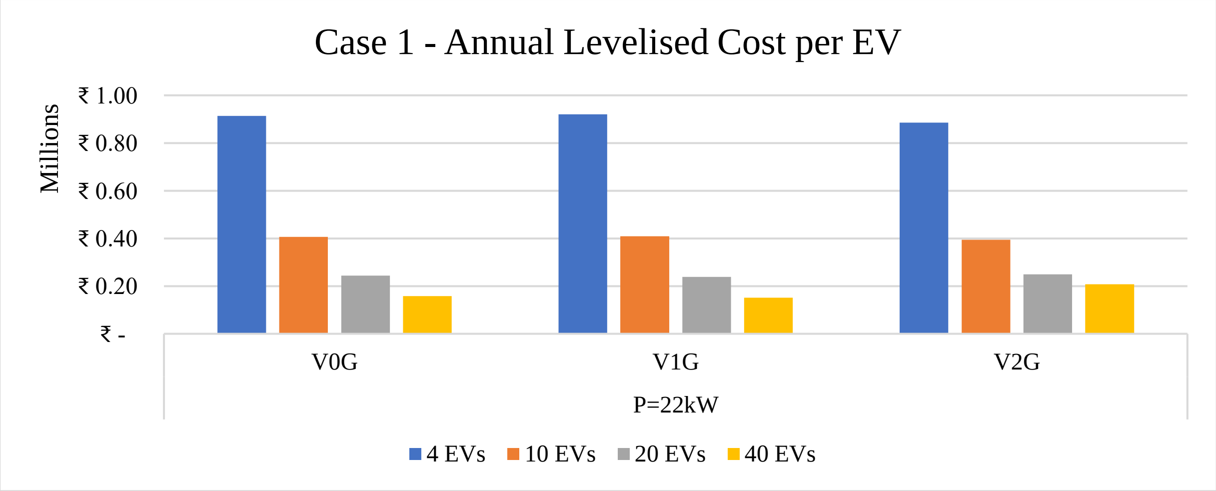

Figure 10:23. Annual levelized cost for case 1 – only grid supply

The operating cost for case 2 is shown in Figure 10:24. It can be observed that the operating cost per day decreases with an increase in the rating of rooftop solar PV. The annual levelized cost per EV, as shown in Figure 10:25, is higher for the V2G case in comparison to the V1G case. The annual levelized cost per EV also decreases with an increase in the rating of rooftop solar PV. The annualized cost per EV also decreases with an increase in the number of EVs.

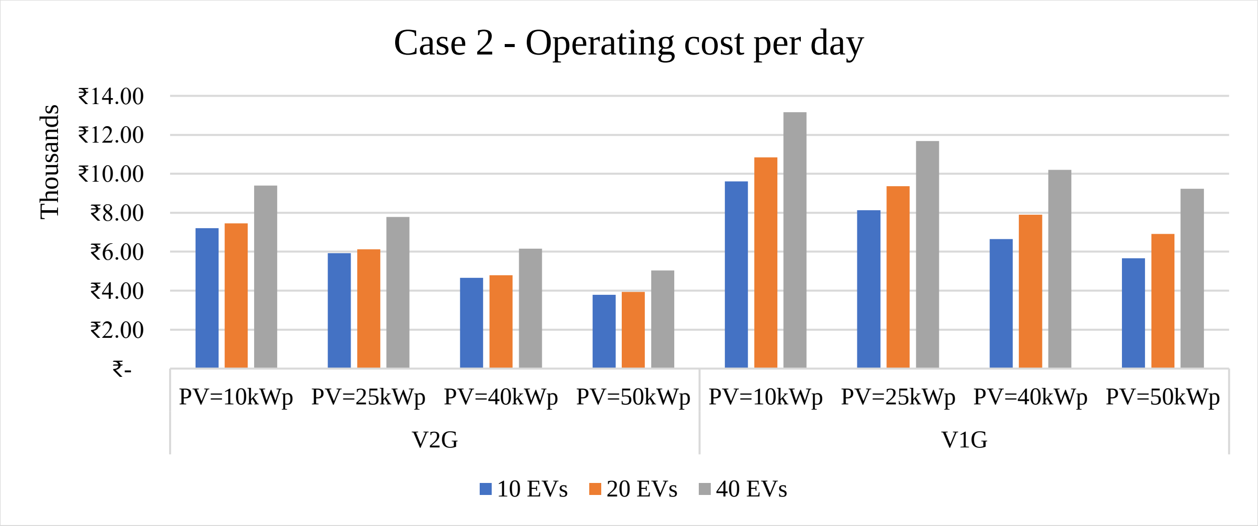

Figure 10:24. Operating cost per day for case 2 – grid supply with rooftop solar PV.

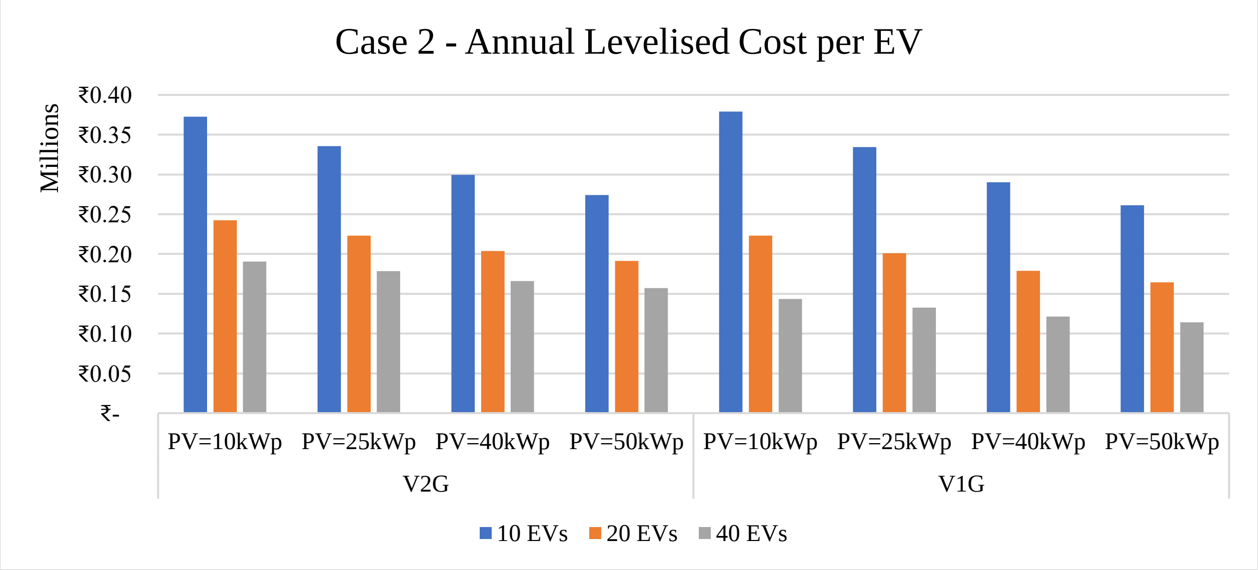

Figure 10:25. Annual levelized cost for case 2 – grid supply with rooftop solar PV.

A surface plot for the second case is presented in Figure 10:26 and Figure 10:27. The energy cost is calculated by varying the rating of rooftop solar PV from 10 kWp to 50 kWp and correspondingly varying the number of EVs from 10 to 40. It can be observed that the operating cost for the V1G case is more than the operating cost for the V2G case. On the contrary, the annual levelized cost is higher for the V2G case in comparison to the V1G case.

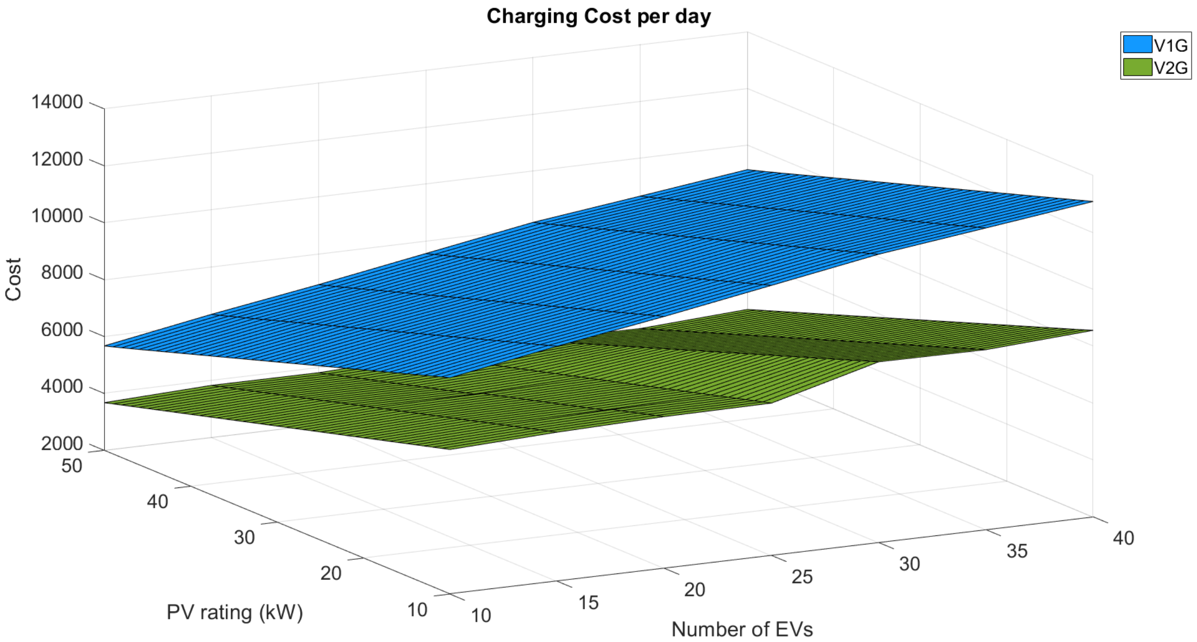

Figure 10:26. Operating cost per day – surface curve for case 2.

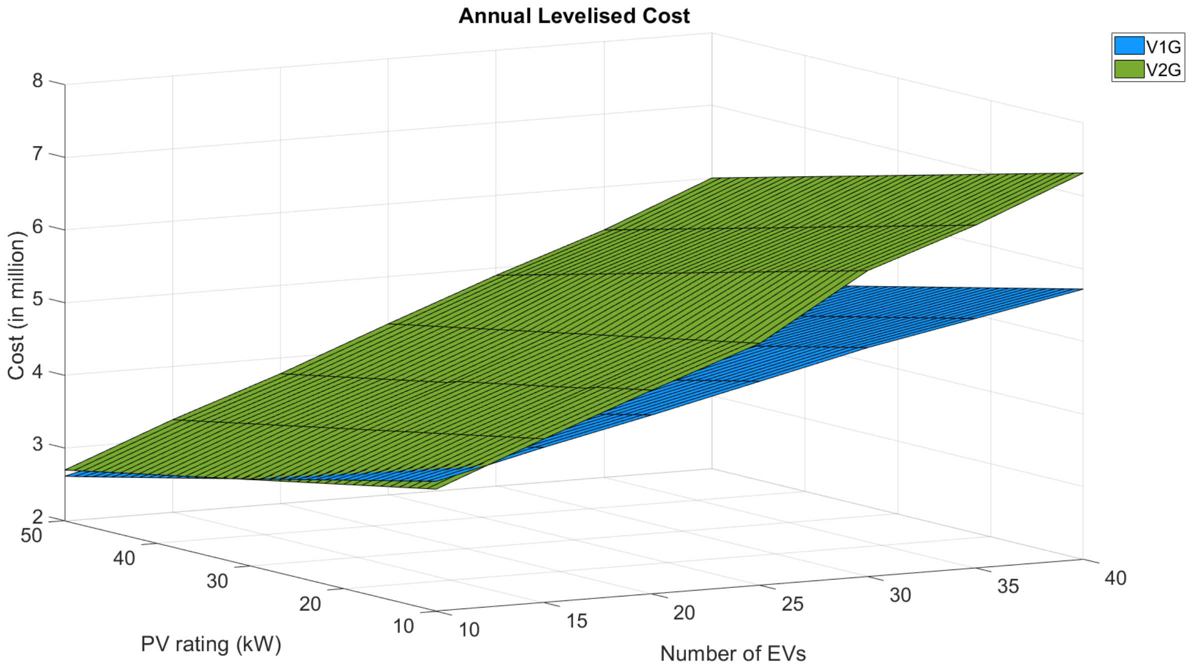

Figure 10:27. Annual levelized – surface curve for case 2.

The operating cost for case 3 is shown in Figure 10:28. It can be observed that the operating cost per day decreases with an increase in the rating of rooftop solar PV and is not affected significantly by a change in the size of the battery storage system. The annual levelized cost per EV for the third case shown in Figure 10*:29* is higher for the V2G case than for the V1G case. The annual levelized cost per EV also decreases with an increase in the rating of rooftop solar PV. The annualized cost per EV also decreases with an increase in the number of EVs. Also, it can be seen that with the increase in battery storage capacity, the operating cost decreases, but there is significant increase in the annualized levelized cost.

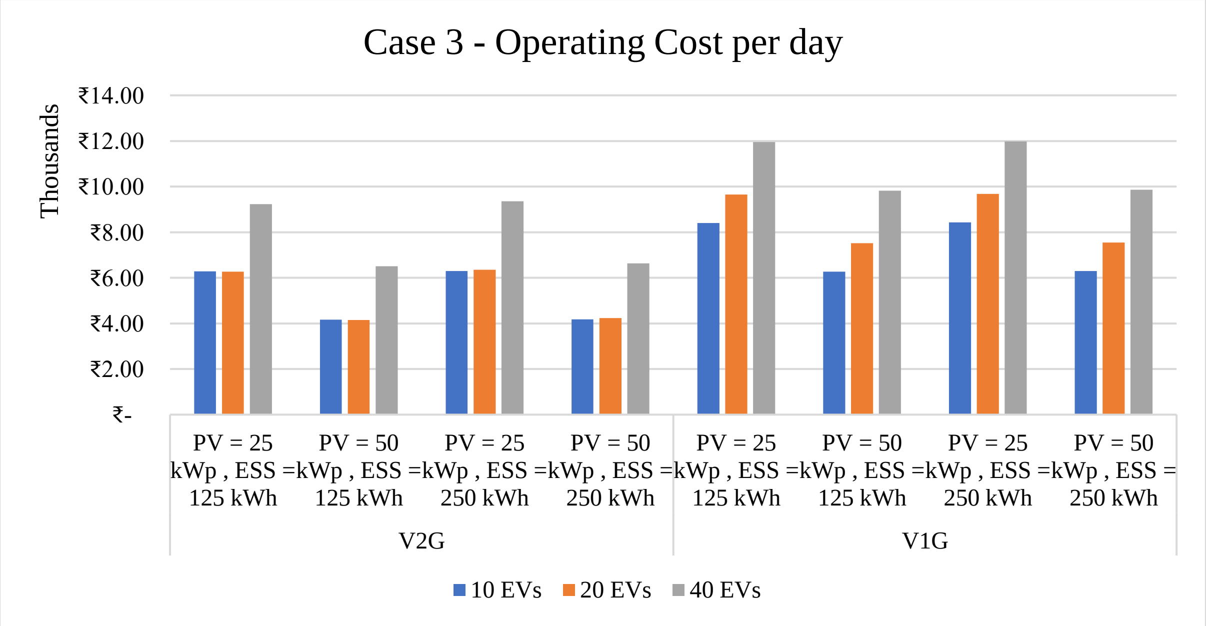

Figure 10:28. Operating cost per day for case 3 – grid supply with rooftop solar PV and stationary battery storage.

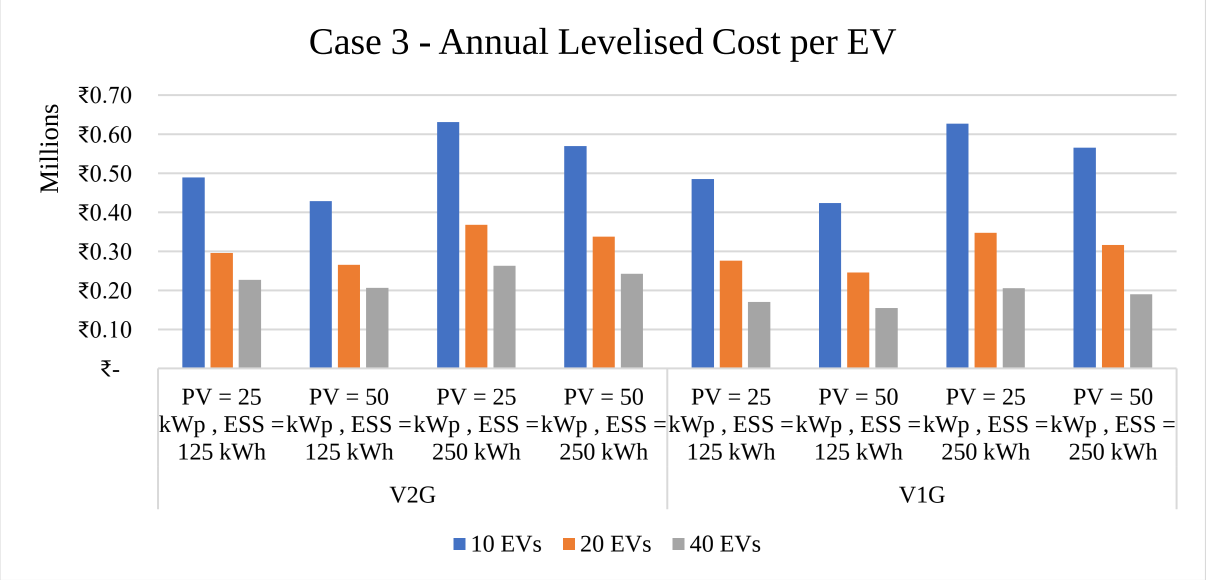

Figure 10:29. Annual levelized cost for case 3 – grid supply with rooftop solar PV and stationary battery storage.

Surface plots for the total annual operating cost and the annual levelized cost per EVfor Case 3 are presented in Figure 10:30 and Figure 10:31 respectively. The energy cost is calculated by varying the rating of rooftop solar PV from 10 kWp to 50 kWp and correspondingly varying the size of battery storage from 100 kWh to 250 kWh. It can be observed that the operating cost increases with an increase in EVs and decreases with an increase in the rating of the rooftop solar PV system. Even with increasing the battery capacity there is marginal decrease in the operating cost, with the decrease in operating cost being higher for lower number of EVs compared to higher number of EVs. Also, beyond 200 kWh of battery storage, the marginal decrease in operating cost lowers. The annual levelized cost per EV decreases with an increase in the number of EVs, as now the flexibility that can be offered by the EV fleet also increases.

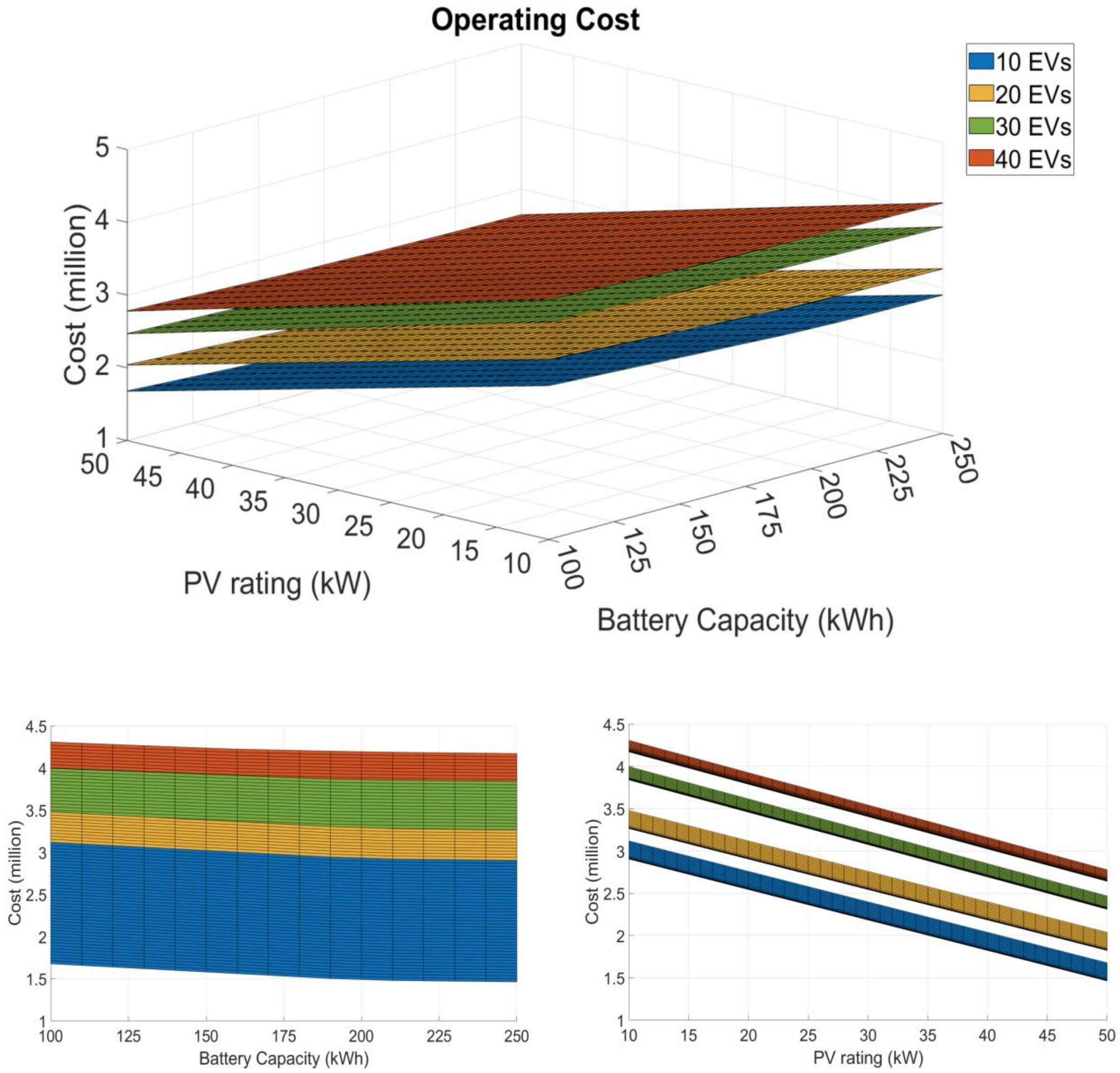

Figure 10:30: Variation of annual operating cost with PV and battery capacity

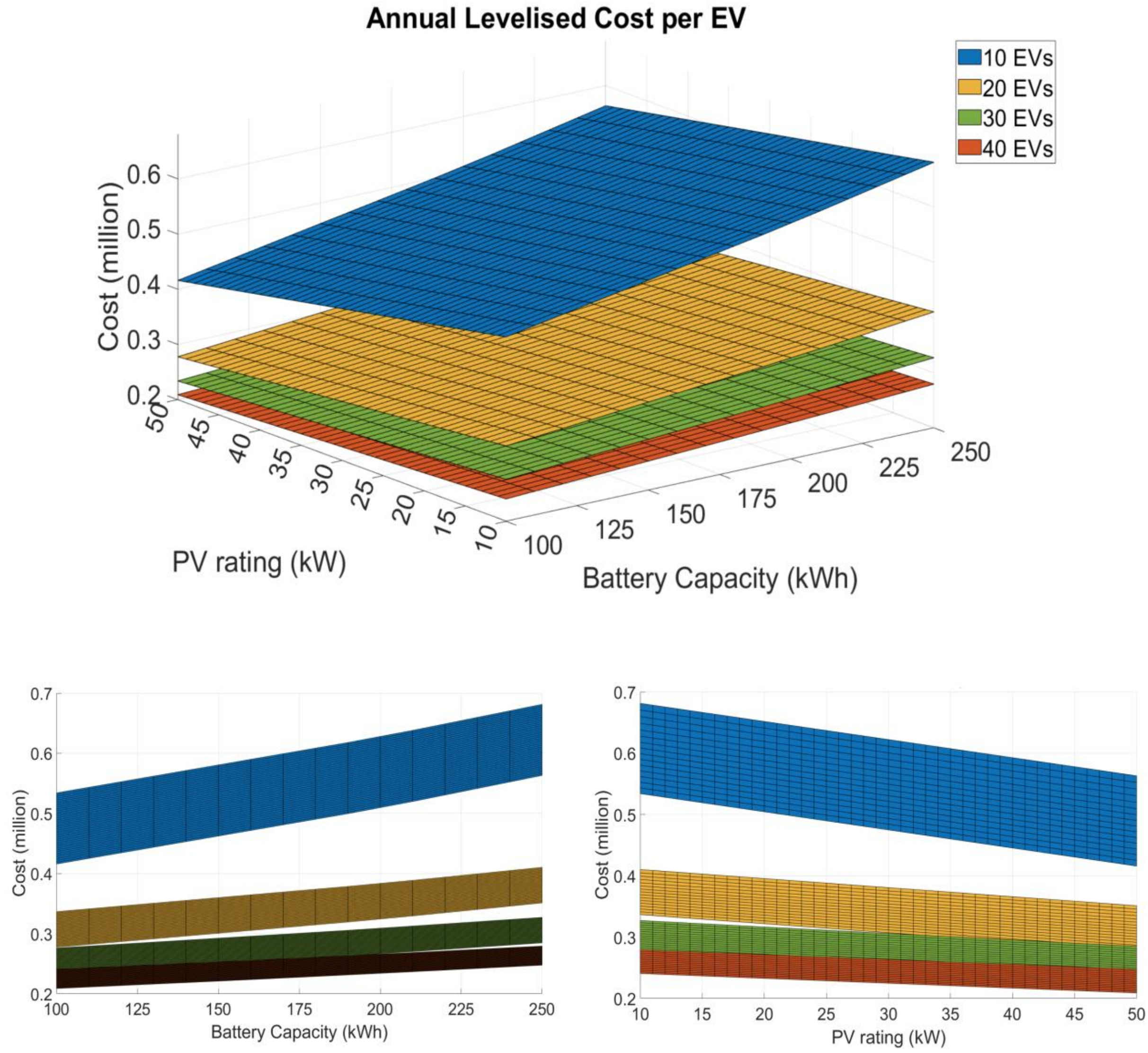

Figure 10:31: Variation of annual levelized cost per EV with PV and battery capacity

The above analysis was extended by considering the non-EV load variation and variation in EV charging behaviour with the month of the year for weekdays and weekends. The commercial non-EV load for different months on weekdays and weekends is shown in Figure 10:32 and Figure 10:33, respectively.

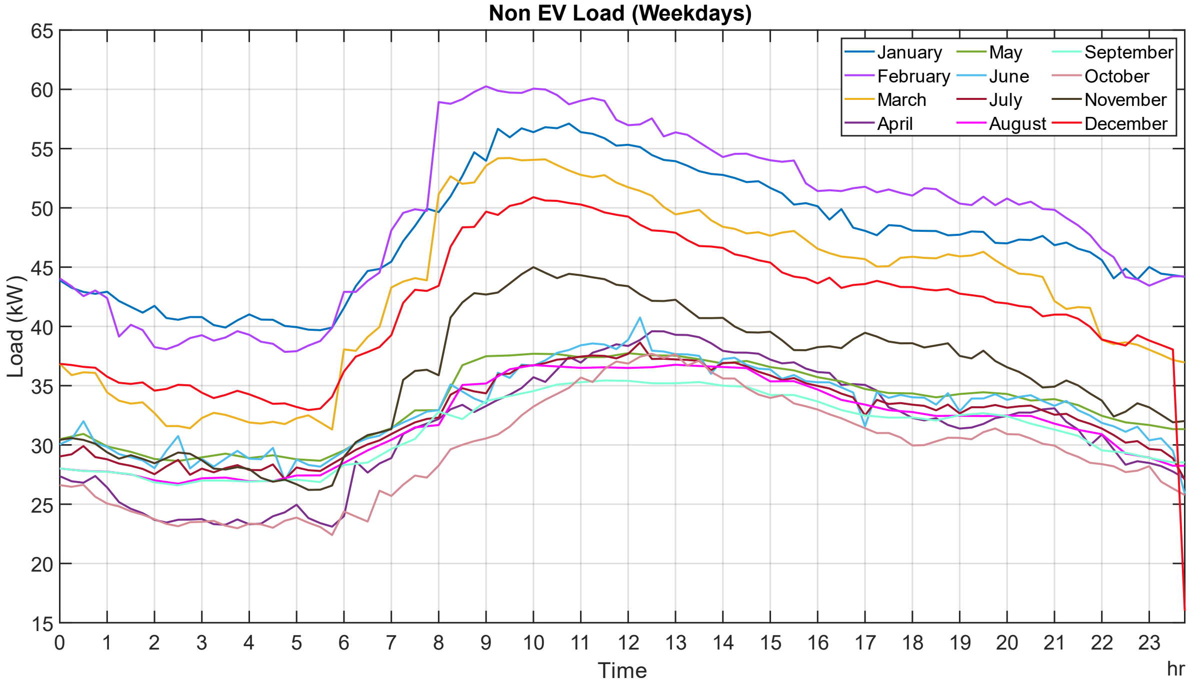

Figure 10:32. Commercial non-EV load curves for weekdays in different months.

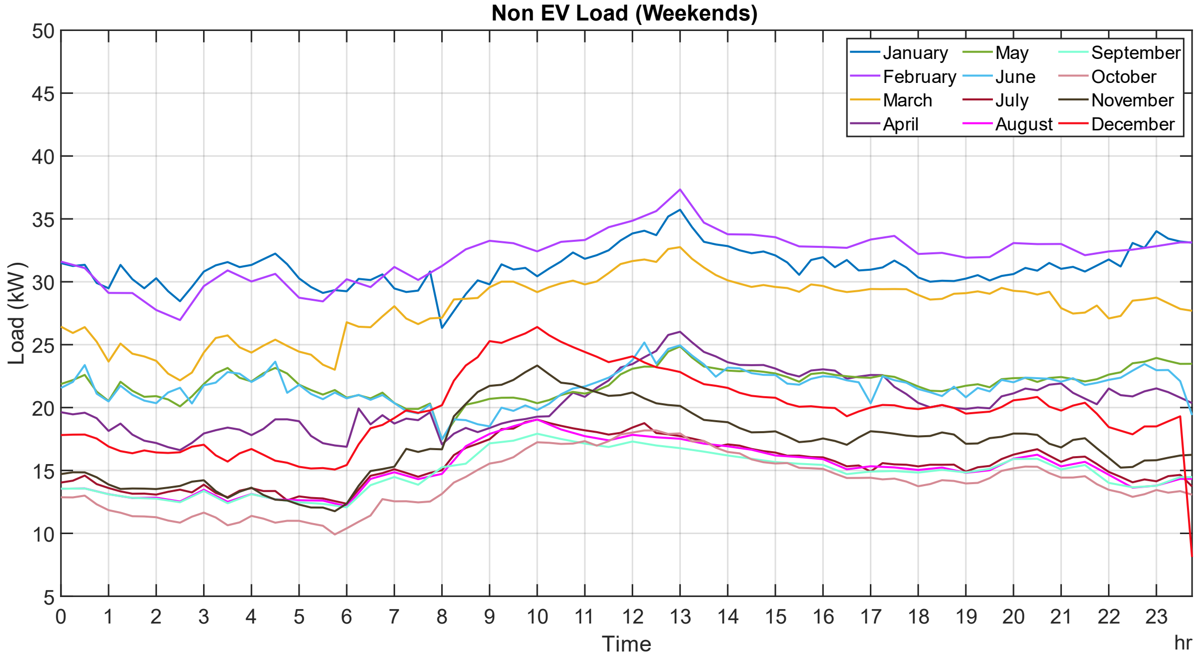

Figure 10:33. Commercial non-EV load curves for weekends in different months.

The resultant EV charging curves for case 3, along with the total load and cost curve, is shown in Figure 10:34 and Figure 10:35, respectively. In this case, a rooftop solar PV with a capacity of 30 kWp and stationary battery storage of 250 kWh with a 50-kW converter is considered. From Figure 10:34 and Figure 10:35, t can be observed that during the peak pricing periods between 9 am to 12 noon and 6 pm to 10 pm, the net load of the building was in negative for all the months of the year, which implies that the collective EV fleet connected to the building was exporting power back to the grid. During the off-peak periods, the EVs get charged, however the total load is constrained to 200 kW, as it is the contracted demand of the building.

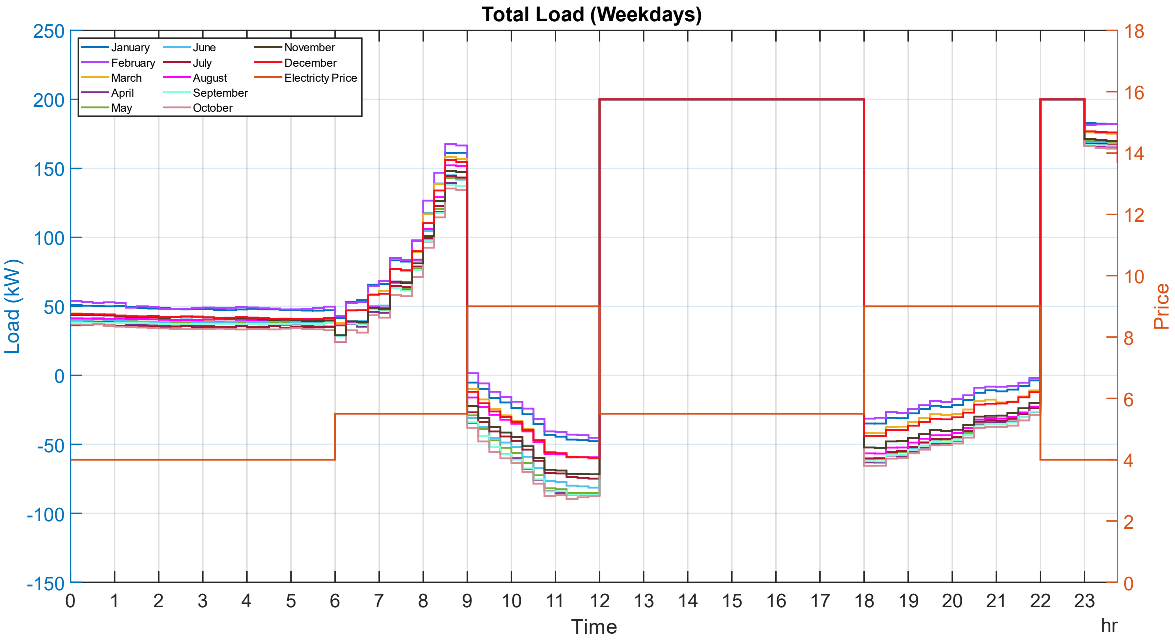

Figure 10:34. Total load of the building on weekdays (including EV load).

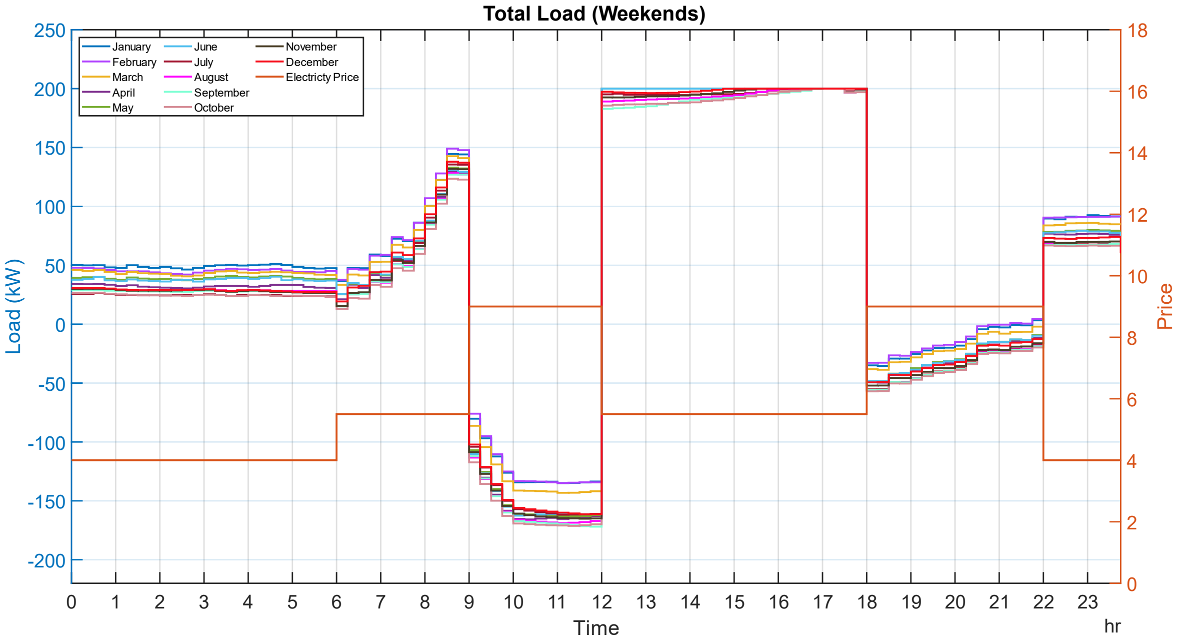

Figure 10:35. Total load of the building on weekends (including EV load).

The operating costs and annual levelized costs for all the three cases are summarised in Table 10.4 Comparison of three cases in terms of operational and annual levelized costs. From the table it can be observed that, similar to V2H scenario, here too the operational cost is highest when the power is supplied just from the grid (Case 1), followed by grid supply along with local rooftop PV (Case 2). The operational cost is lowest for when battery storage is also added to the system (Case 3). 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 10.12: 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 (EUR 165.82)	5157809 (EUR 60523.46)
Case 2: Grid Supply + PV System (30 kWp)	11,824.46 (EUR 137.85)	4509622 (EUR 52917.41)
Case 3: Grid Supply + PV System(2kWp) + Battery Storage (250 kWh)	11,773.22 (EUR 138.15)	7302700 (EUR 85692.33)

The analysis was extended to residential building and commercial building like mall, with inclusion of the non-EV load variation and variation in EV charging behaviour with the month of the year for weekdays and weekends.

The non-EV load of a mall for different months on weekdays and weekends is shown in Figure 10:36 and Figure 10:*37*, respectively. The resultant EV charging curves for case 3, along with the total load and cost curve, is shown in Figure 10:38 and Figure 10:39, respectively. In this case, a rooftop solar PV with a capacity of 125 kWp and stationary battery storage of 1000 kWh with a 50-kW converter is considered. The operating costs and annual levelized costs for all the three cases are summarised in Table 10.13.

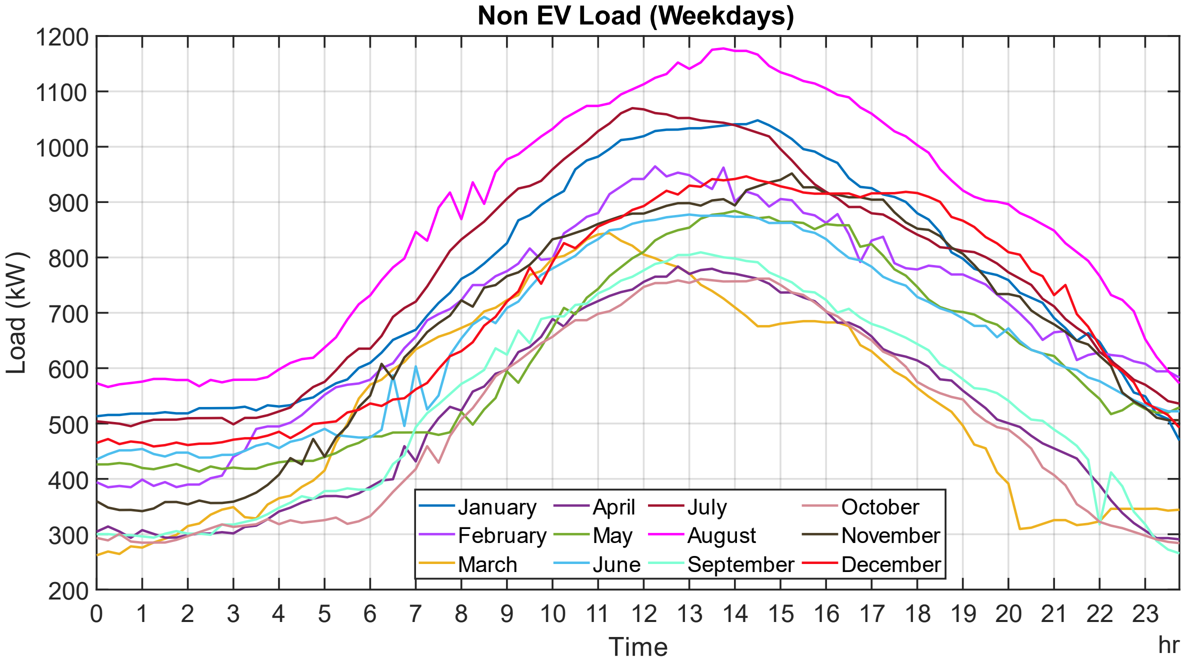

Figure 10:36. Shopping mall building non-EV load curves for weekdays in different months[124].

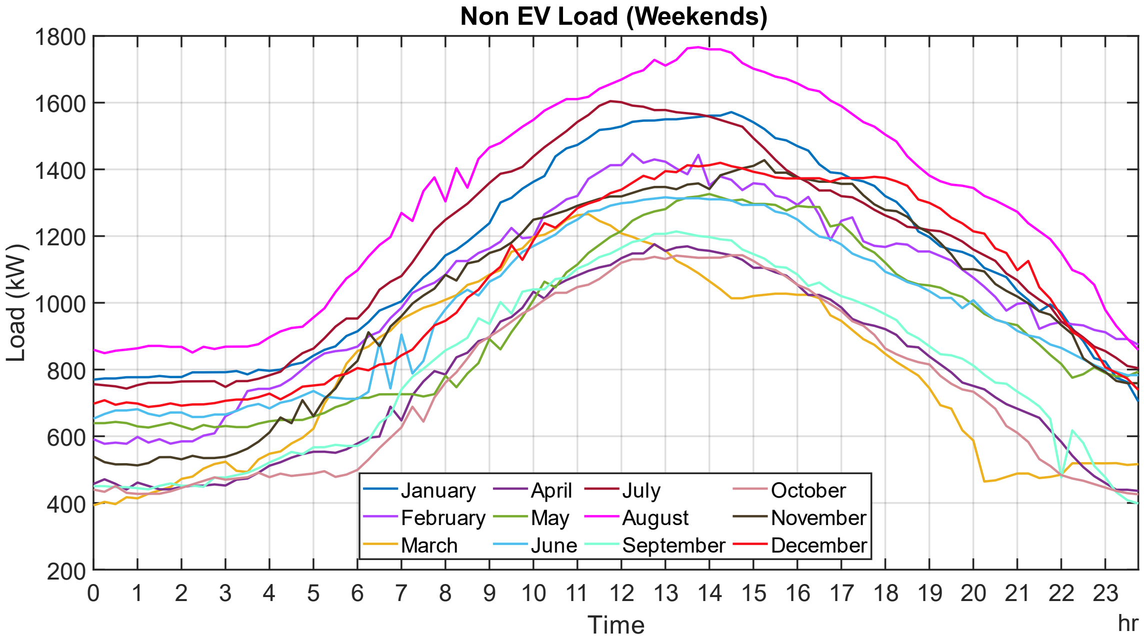

Figure 10:37. Shopping mall building non-EV load curves for weekends in different months124.

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[124] Aristontelis Giannopoulos, "Energy systems optimization of a Shopping mal", Master's thesis, Imperial College London, 2008.

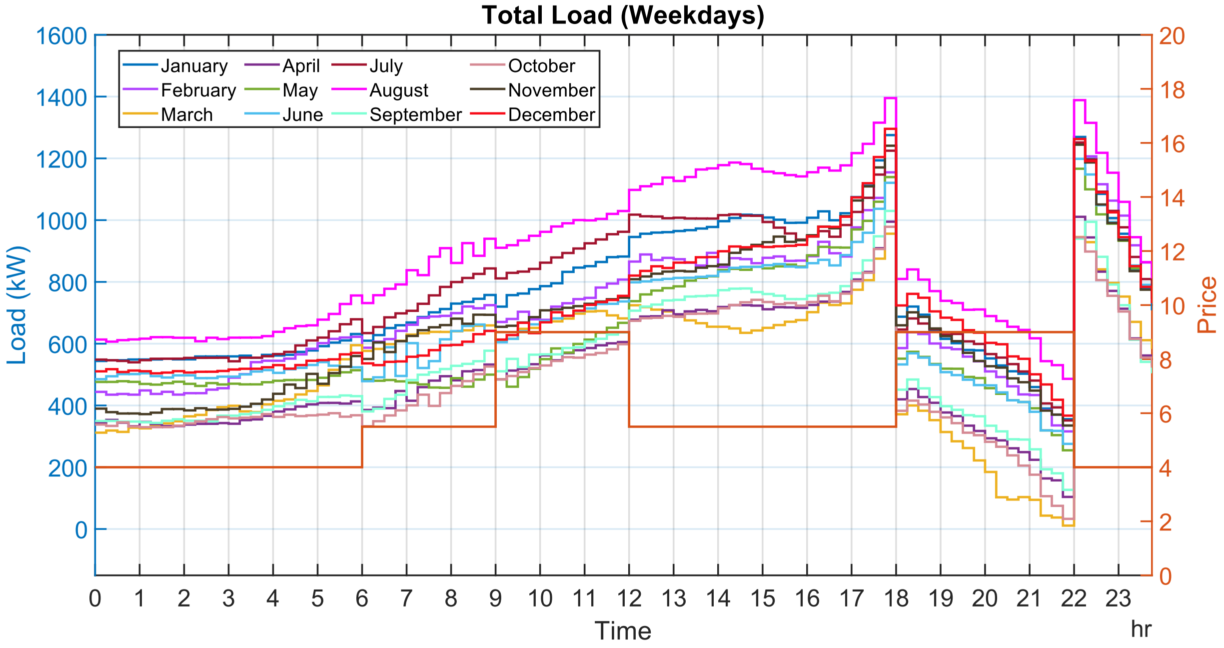


Figure 10:38. Total load of the shopping mall on weekdays (including EV load).

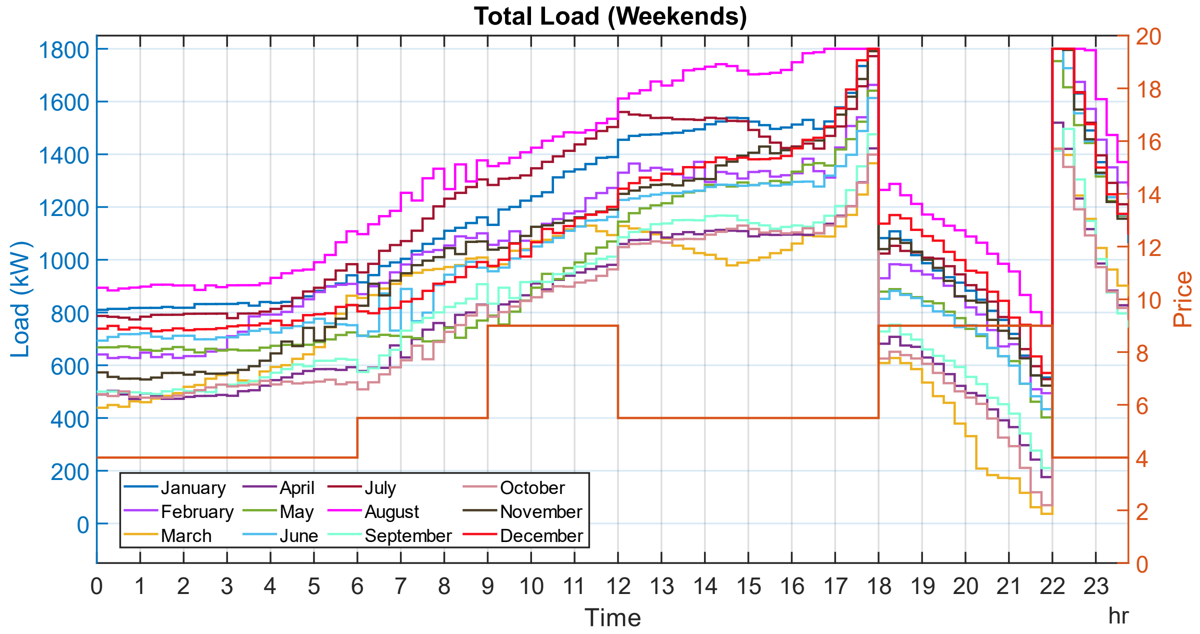


Figure 10:39. Total load of the shopping mall on weekends (including EV load).

Table 10.13. 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	259375.02 (EUR 3043.59)	94671882 (EUR 1110911.55)
Case 2: Grid Supply + PV System (125 kWp)	251461.77 (EUR 2950.74)	92591081 (EUR 1086494.73)
Case 3: Grid Supply + PV System(125kWp) + Battery Storage (1000 kWh)	250066.08 (EUR 2934.36)	103328297 (EUR 1212488.82)

The non-EV load of a residential building for different months on weekdays and weekends is shown in Figure 10*:41* and Figure 10*:42*, respectively. The resultant EV charging curves for case 3, along with the total load and cost curve, is shown in Figure 10:43 and Figure 10:44, respectively. In this case, a rooftop solar PV with a capacity of 75 kWp and stationary battery storage of 300 kWh with a 50-kW converter is considered. The operating costs and annual levelized costs for all the three cases are summarised in Table 10.14

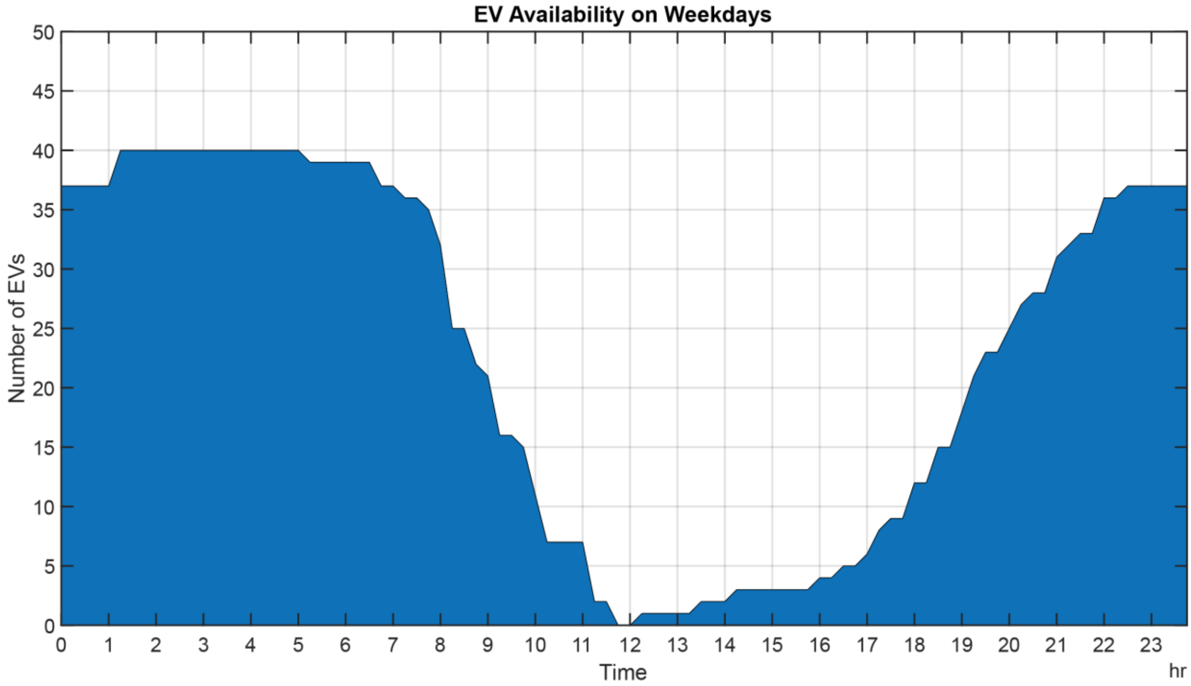


Figure 10:40: EV availability in residential complex furing weekdays

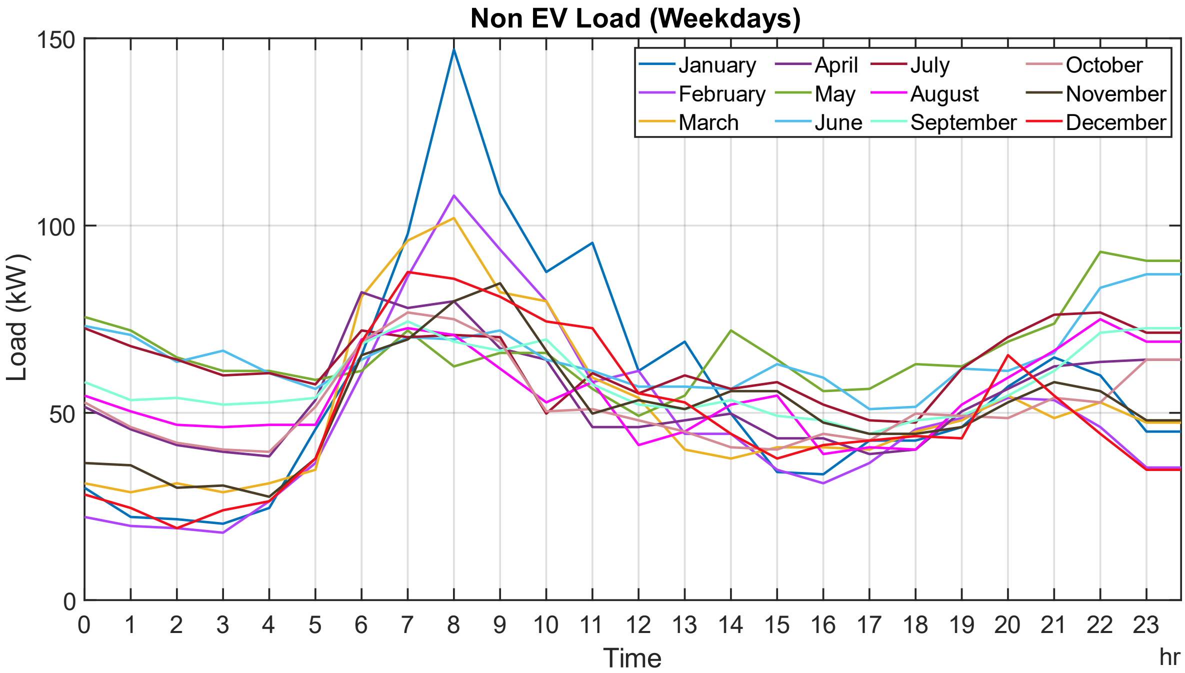


Figure 10:41. Residential building non-EV load curves for weekdays in different months117.

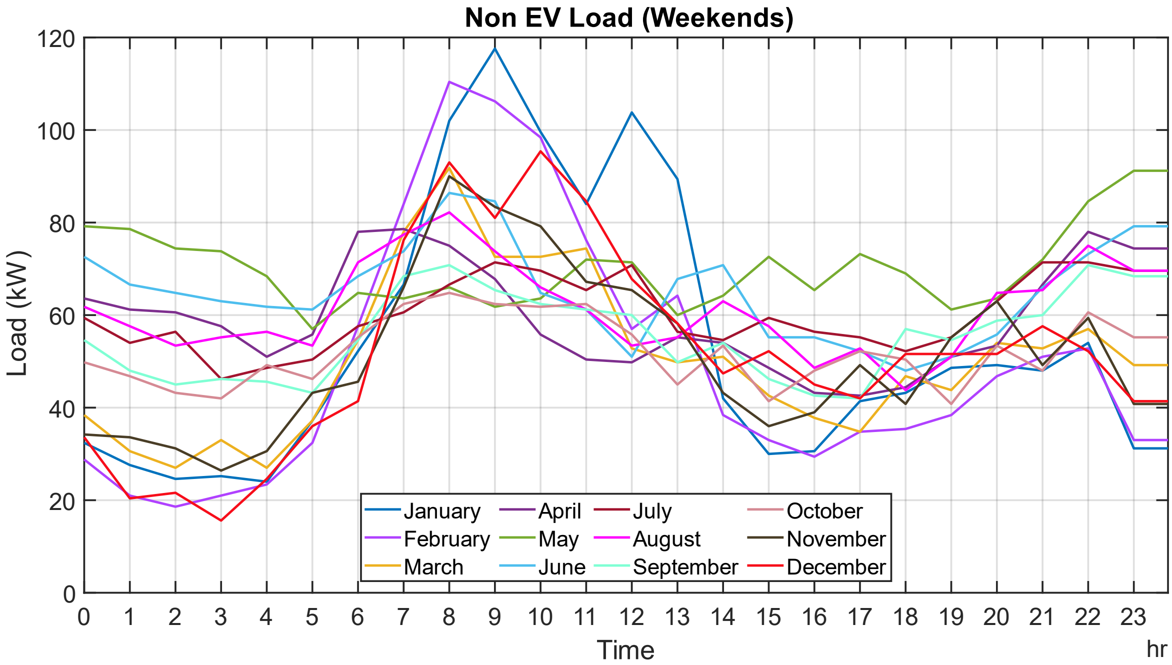


Figure 10:42. Residential building non-EV load curves for weekends in different months117.

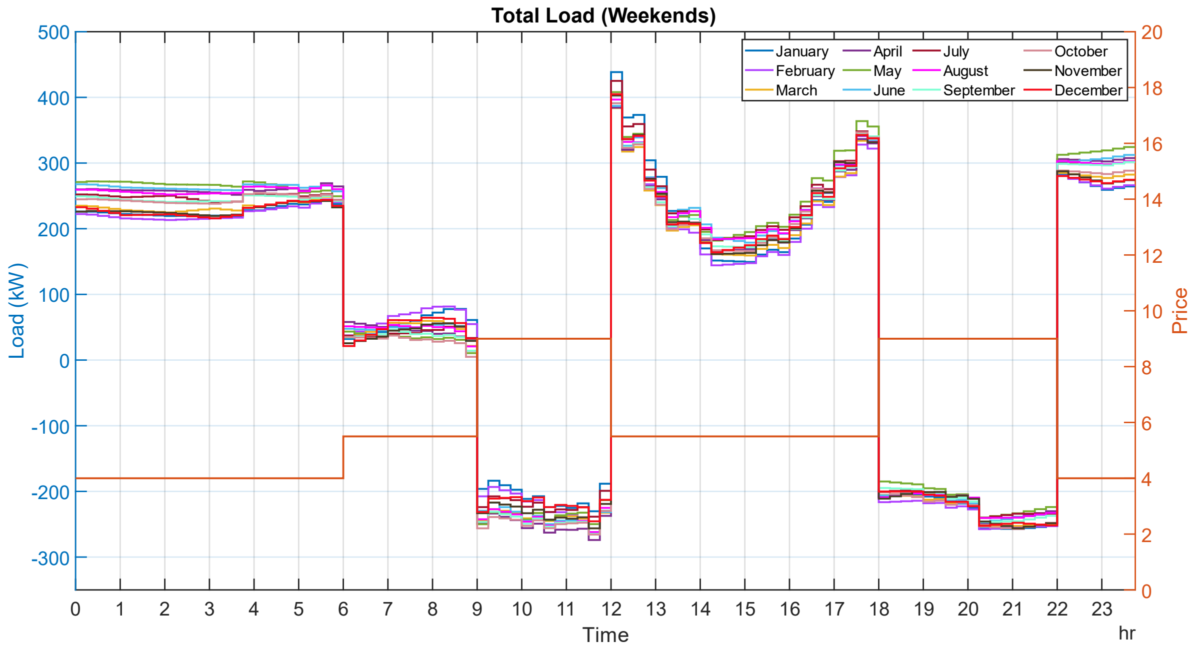


Figure 10:43. Total load of the residential building on weekdays (including EV load).

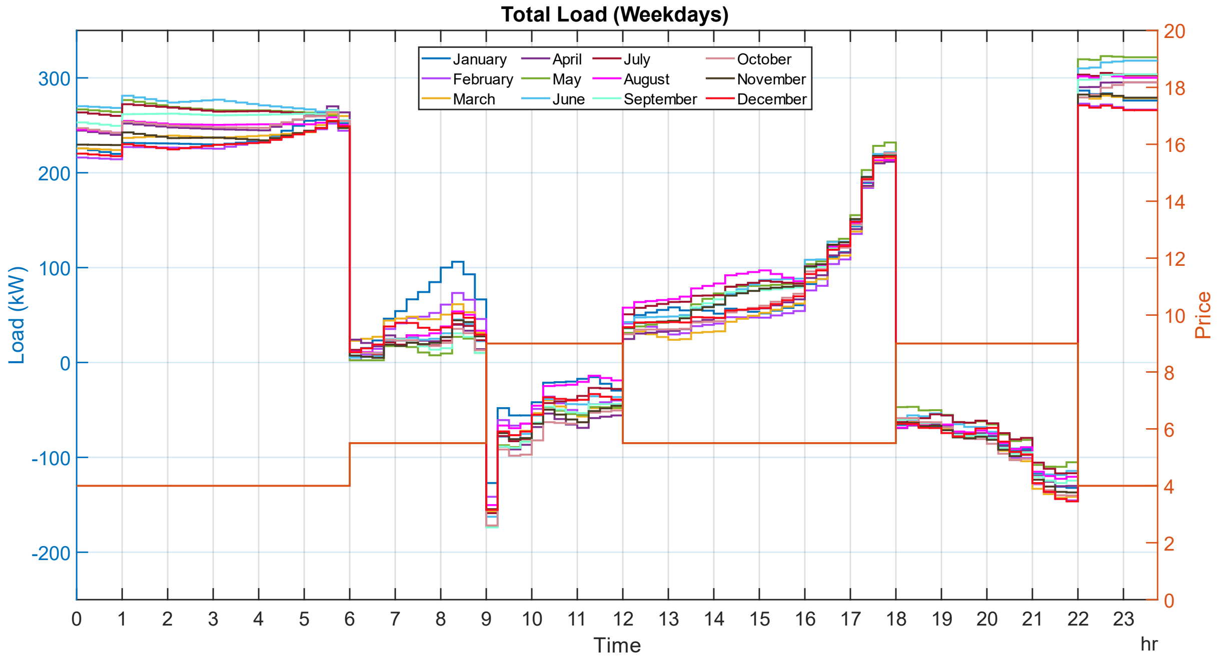


Figure 10:44. Total load of the residential building on weekends (including EV load).

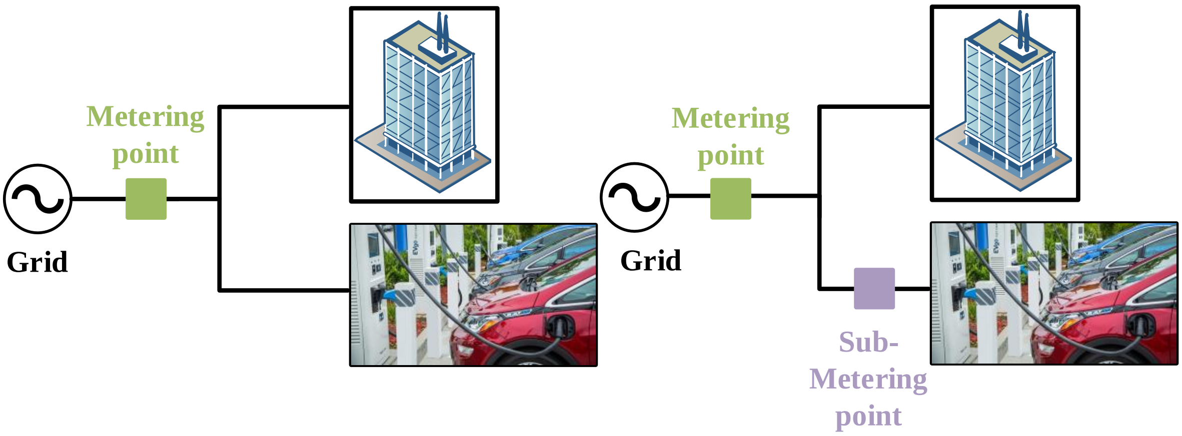
Table 10.14. Operational and annual levelized cost for the 3 considered cases for residential building

Case	Operational Cost (INR/year)	Annual Levelized Cost (in INR)
Case 1: Only Grid Supply	19574.17 (EUR 229.69)	7144573 (EUR 83836.81)
Case 2: Grid Supply + PV System (30 kWp)	14826.22 (EUR 173.98)	5896093 (EUR 69186.73)
Case 3: Grid Supply + PV System(30kWp) + Battery Storage (250 kWh)	13847.28 (EUR 162.49)	8912769 (EUR 104585.41)

10.3.3 Different Metering Arrangements

The effect of metering connections on EV charging/discharging schedules is studied in this section. The operating cost varies significantly with changes in metering types. Two types of metering shown in Figure 10:45 are analysed in this section –

1. Separate metering for EV load and Building
2. Same metering for EV load and Building



Same Metering *Sub Metering*

Figure 10:45. Different types of metering.

10.3.3.1 Sub-metering for EV load and Building

The EV charging load is metered at the EV charging tariff, whereas the rest of the load is metered at the commercial tariff. The operating cost per day and the annual levelized cost for this case are shown in Figure 10:46 and Figure 10:47, respectively.

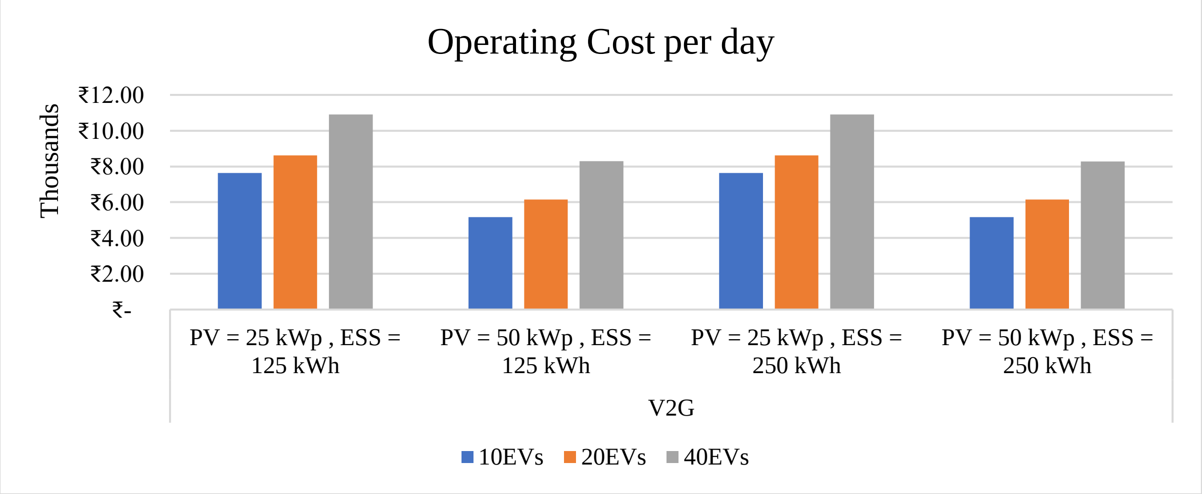


Figure 10:46. Operating cost per day for case 3 with separate metering.

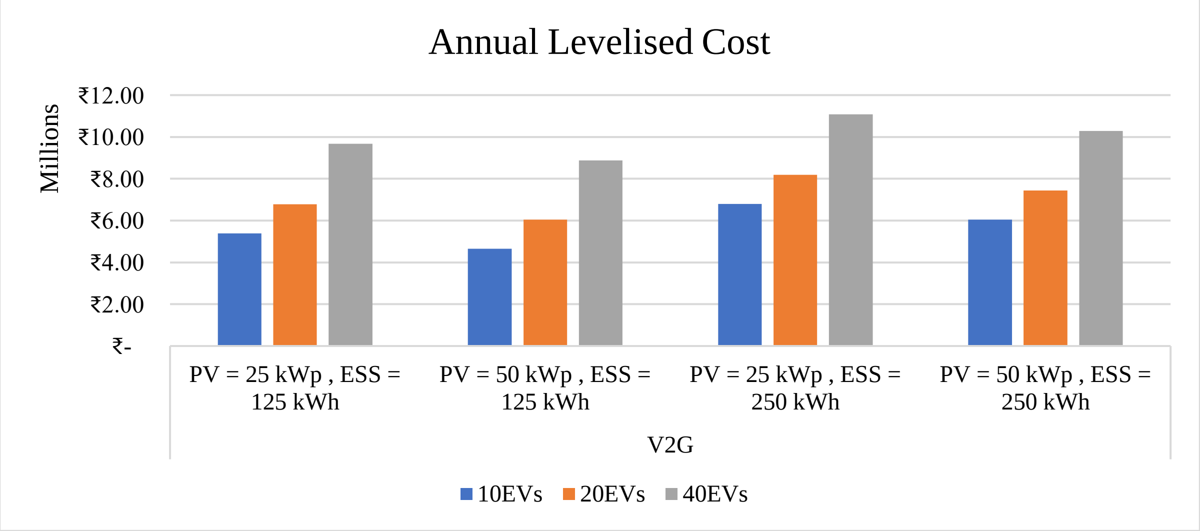


Figure 10:47. Annual levelized cost for case 3 with separate metering.

10.3.3.2 Same metering for EV load and Building

In this case, all the loads are connected through the same metering. The metering will be done as per the commercial tariff. The operating cost per day and the annual levelized cost for metering at commercial tariff are shown in Figure 10:48 and Figure 10:49, respectively.

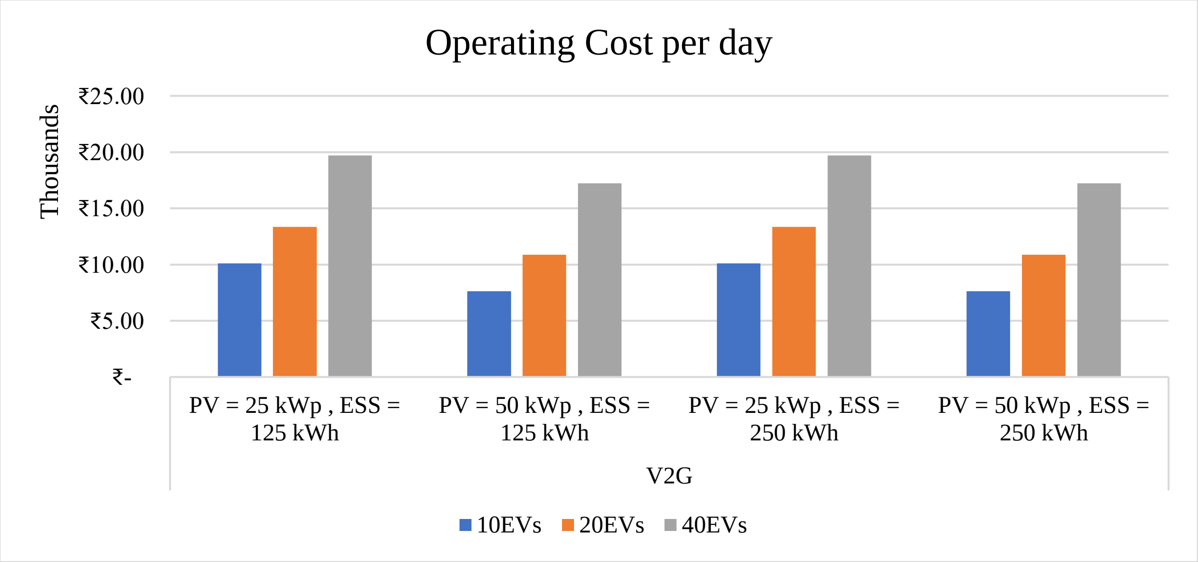


Figure 10:48. Operating cost per day for case 3 with same metering at commercial tariff.

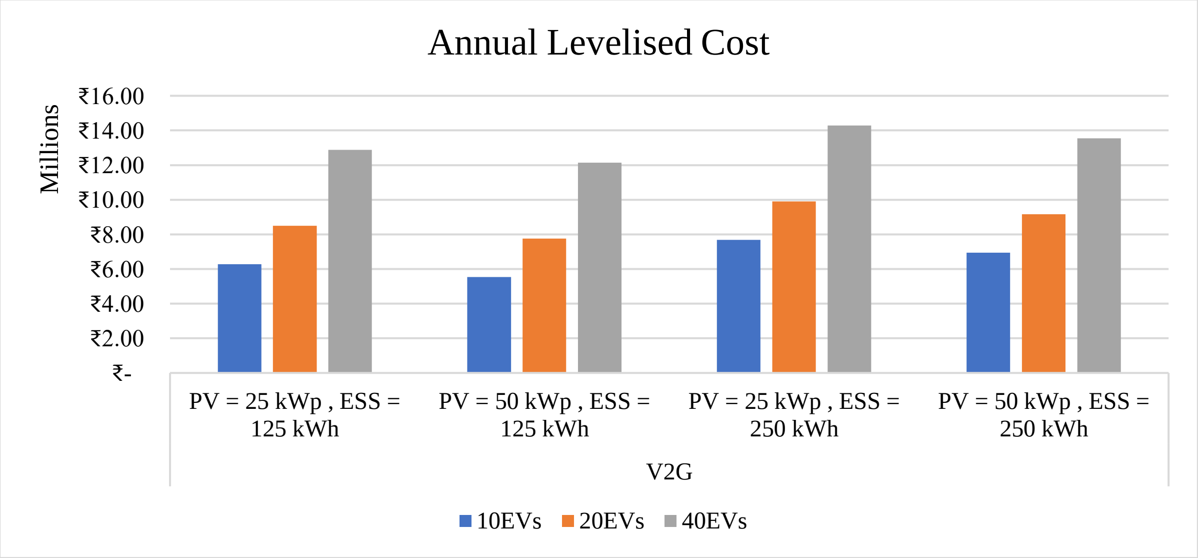


Figure 10:49. Annual levelized cost for case 3 with the same metering at commercial tariff

The operating cost per day increases with an increase in number of EVs and reduces with increase in the capacity of solar PV. It can be observed that the operating cost per day is higher in this scenario compared to separate metering scenario because the EV load is also billed at commercial tariff. This decreases the discharging of EVs as they will have to be charged at a higher price. The overall energy cost increases with same metering for non EV load and EV load. Therefore, separate metering to supply EV load is necessary to bill EV load at EV tariff.

10.3.4 Dimensional Analysis

Different comparisons have been performed to arrive at the optimal design of V2B. As shown in Table 10.15, 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. From Table 10.15 and Table 10.16, it can be observed that with increasing number of vehicles, the operational cost of building (i.e. the energy costs) increases for dumb charging (V0G). Compared to dumb charging, the operational cost of smart charging is lower and still lower with V2B. With PV also added to the system, the operational cost is further lowered. So, by utilizing V2B, the building operator/manager can potentially reduce their operational cost i.e. increase their savings on the energy cost. The annual savings that can be made by switching to smart charging and bidirectional charging from dumb charging is given in Table 10.17. If the maximum contracted demand of the property is restricted, the annual savings that can be made from switching to V2G from V0G is around INR 15.72 lakhs for 40 vehicles with only grid supply and INR 21.03 lakhs with addition of 50 kWp rooftop PV. However, if the contracted demand capacity of the property is increased, the vehicles could be used more effectively to shift the energy usage from peak to off-peak pricing periods. As a result, the annual savings increased to INR 38.79 lakhs for 40 vehicles with only grid supply and INR 35.59 lakhs with addition of rooftop PV. Considering a discount rate of 10% and an operational timeframe of 10 years, the NPV of the annual savings has been given in Table 10.18. As can be observed, transition from dumb charging to bidirectional charging gave the highest savings for the building operator/manager. However, to facilitate smart charging or bidirectional charging the building operator also needs to invest in chargers capable of such functionalities. So there is an incremental cost for the building operator to facilitate these services, which is shown in Table 10.20. As expected, since the cost of bidirectional chargers is the highest, the increment in the capital expenditure to facilitate bidirectional charging is also very high. So, the question that needs to be answered here is whether the increment in capital expenditure is justified based on the annual savings made. The difference between the increment in capital expenditure and the NPV of the annual savings due to the respective switch to V2G/V1G considering 10 years of operational life is given in Table 10.19. 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, bidirectional charging shows higher net savings. 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[125], the total savings are significantly increased making the business case financially viable. The relationship between the different concerned parameters is shown in

Figure 10:50, which shows that shifting from V0G to V1G is always sensible as the potential savings outweigh 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 need to be taken into consideration.

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[125] 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.

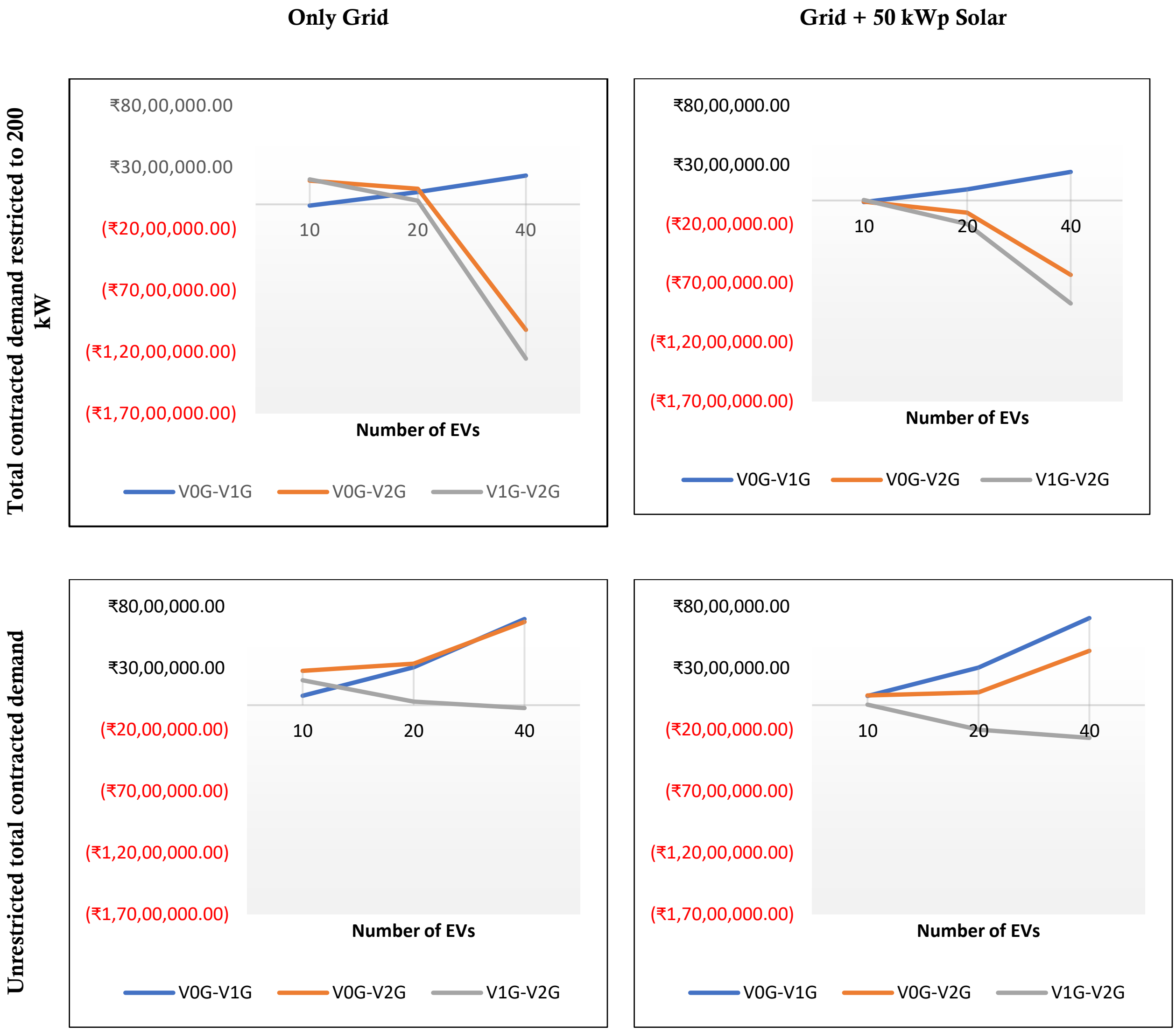

Figure 10:50: Difference between increment in capital expenditure and NPV of savings considering 10 years of operational lifetime

Table 10.15: Daily operational cost

Daily Operation Cost in INR												
	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	₹ 10,719	₹ 12,540	₹ 15,732	₹ 5,787	₹ 7,608	₹ 10,800	₹ 11,041	₹ 13,318	₹ 17,468	₹ 6,116	₹ 8,388	₹ 12,536
V1G	₹ 10,589	₹ 11,837	₹ 14,190	₹ 5,669	₹ 6,918	₹ 9,229	₹ 10,589	₹ 11,837	₹ 14,190	₹ 5,670	₹ 6,918	₹ 9,229
V2G	₹ 7,974	₹ 8,011	₹ 11,423	₹ 3,794	₹ 3,942	₹ 5,036	₹ 7,975	₹ 8,012	₹ 6,839	₹ 3,795	₹ 3,942	₹ 2,783
Daily Operational Cost in EUR												
	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	€ 126	€ 147	€ 185	€ 68	€ 89	€ 127	€ 130	€ 156	€ 205	€ 72	€ 98	€ 147
V1G	€ 124	€ 139	€ 167	€ 67	€ 81	€ 108	€ 124	€ 139	€ 167	€ 67	€ 81	€ 108
V2G	€ 94	€ 94	€ 134	€ 45	€ 46	€ 59	€ 94	€ 94	€ 80	€ 45	€ 46	€ 33

Table 10.16: Annual operating cost

Annual Operational Cost in INR												
	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	₹ 39,12,435	₹ 45,77,100	₹ 57,42,180	₹ 21,12,218	₹ 27,76,883	₹ 39,41,963	₹ 40,29,955	₹ 48,61,060	₹ 63,75,719	₹ 22,32,171	₹ 30,61,567	₹ 45,75,502
V1G	₹ 38,64,985	₹ 43,20,505	₹ 51,79,350	₹ 20,69,185	₹ 25,25,070	₹ 33,68,585	₹ 38,64,826	₹ 43,20,377	₹ 51,79,218	₹ 20,69,489	₹ 25,25,040	₹ 33,68,648
V2G	₹ 29,10,510	₹ 29,24,015	₹ 41,69,395	₹ 13,84,810	₹ 14,38,830	₹ 18,38,140	₹ 29,10,718	₹ 29,24,308	₹ 24,96,152	₹ 13,85,006	₹ 14,38,819	₹10,15,714
Annual Operational Cost in EUR												
	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	€ 45,910	€ 53,709	€ 67,381	€ 24,785	€ 32,585	€ 46,256	€ 47,289	€ 57,041	€ 74,815	€ 26,193	€ 35,925	€ 53,690
V1G	€ 45,353	€ 50,698	€ 60,776	€ 24,281	€ 29,630	€ 39,528	€ 45,351	€ 50,697	€ 60,775	€ 24,284	€ 29,630	€ 39,529
V2G	€ 34,153	€ 34,311	€ 48,925	€ 16,250	€ 16,884	€ 21,569	€ 34,155	€ 34,315	€ 29,291	€ 16,252	€ 16,884	€ 11,919

Table 10.17: Annual Savings

Annual Savings in INR												
	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	₹ 47,450	₹ 2,56,595	₹ 5,62,830	₹ 43,033	₹ 2,51,813	₹ 5,73,378	₹ 1,65,129	₹ 5,40,683	₹ 11,96,501	₹ 1,62,683	₹ 5,36,527	₹ 12,06,854
V0G →V2G	₹ 10,01,925	₹ 16,53,085	₹ 15,72,785	₹ 7,27,408	₹ 13,38,053	₹ 21,03,823	₹ 11,19,237	₹ 19,36,752	₹ 38,79,567	₹ 8,47,165	₹ 16,22,747	₹ 35,59,788
V1G →V2G	₹ 9,54,475	₹ 13,96,490	₹ 10,09,955	₹ 6,84,375	₹ 10,86,240	₹ 15,30,445	₹ 9,54,108	₹ 13,96,068	₹ 26,83,066	₹ 6,84,482	₹ 10,86,220	₹ 23,52,935
Annual Savings in EUR												
	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	€ 557	€ 3,011	€ 6,604	€ 505	€ 2,955	€ 6,728	€ 1,938	€ 6,345	€ 14,040	€ 1,909	€ 6,296	€ 14,162
V0G →V2G	€ 11,757	€ 19,398	€ 18,456	€ 8,536	€ 15,701	€ 24,687	€ 13,134	€ 22,726	€ 45,524	€ 9,941	€ 19,042	€ 41,772
V1G →V2G	€ 11,200	€ 16,387	€ 11,851	€ 8,031	€ 12,746	€ 17,959	€ 11,196	€ 16,382	€ 31,484	€ 8,032	€ 12,746	€ 27,610

Table 10.18: NPV of savings for 10 years

NPV of savings for 10 years in INR												
	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	₹ 3,49,236	₹ 18,88,562	₹ 41,42,478	₹ 3,16,725	₹ 18,53,364	₹ 42,20,110	₹ 12,15,367	₹ 39,79,476	₹ 88,06,348	₹ 11,97,358	₹ 39,48,884	₹ 88,82,547
V0G →V2G	₹ 73,74,255	₹ 1,21,66,850	₹ 1,15,75,835	₹ 53,53,785	₹ 98,48,185	₹ 1,54,84,319	₹ 82,37,683	₹ 1,42,54,661	₹ 2,85,53,951	₹ 62,35,208	₹ 1,19,43,561	₹ 2,62,00,351
V1G →V2G	₹ 70,25,019	₹ 1,02,78,288	₹ 74,33,357	₹ 50,37,060	₹ 79,94,821	₹ 1,12,64,208	₹ 70,22,316	₹ 1,02,75,185	₹ 1,97,47,603	₹ 50,37,850	₹ 79,94,677	₹ 1,73,17,804
NPV of savings for 10 years in EUR												
	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	€ 4,098	€ 22,161	€ 48,609	€ 3,717	€ 21,748	€ 49,520	€ 14,262	€ 46,697	€ 1,03,337	€ 14,050	€ 46,338	€ 1,04,231
V0G →V2G	€ 86,532	€ 1,42,770	€ 1,35,835	€ 62,823	€ 1,15,562	€ 1,81,698	€ 96,664	€ 1,67,269	€ 3,35,062	€ 73,166	€ 1,40,150	€ 3,07,444
V1G →V2G	€ 82,434	€ 1,20,609	€ 87,226	€ 59,107	€ 93,814	€ 1,32,178	€ 82,402	€ 1,20,572	€ 2,31,725	€ 59,116	€ 93,812	€ 2,03,213

Table 10.19: Difference between increment in capital expenditure and NPV of savings considering 10 years of operational lifetime

In INR												
	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	₹ -1,00,764	₹ 9,88,562	₹ 23,42,478	₹ -1,33,275	₹ 9,53,364	₹ 24,20,110	₹ 7,65,367	₹ 30,79,476	₹ 70,06,348	₹ 7,47,358	₹ 30,48,884	₹ 70,82,547
V0G →V2G	₹ 19,29,255	₹ 12,76,850	₹ -1,02,04,165	₹ -91,215	₹ -10,41,815	₹ -62,95,681	₹ 27,92,683	₹ 33,64,661	₹ 67,73,951	₹ 7,90,208	₹ 10,53,561	₹ 44,20,351
V1G →V2G	₹ 20,30,019	₹ 2,88,288	₹ -1,25,46,643	₹ 42,060	₹ -19,95,179	₹ -87,15,792	₹ 20,27,316	₹ 2,85,185	₹ -2,32,397	₹ 42,850	₹ -19,95,323	₹ -26,62,196
in EUR												
	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	€ -1,182	€ 11,600	€ 27,487	€ -1,564	€ 11,187	€ 28,398	€ 8,981	€ 36,136	€ 82,215	€ 8,770	€ 35,777	€ 83,109
V0G →V2G	€ 22,639	€ 14,983	€ -1,19,739	€ -1,070	€ -12,225	€ -73,876	€ 32,770	€ 39,482	€ 79,488	€ 9,273	€ 12,363	€ 51,870
V1G →V2G	€ 23,821	€ 3,383	€ -1,47,227	€ 494	€ -23,412	€ -1,02,274	€ 23,789	€ 3,346	€ -2,727	€ 503	€ -23,414	€ -31,239

Table 10.20: Incremental cost of charger procurement

Incremental cost of charger procurement in INR			
Number of EVs	**10**	**20**	**40**
V0G →V1G	₹ 4,50,000	₹ 9,00,000	₹ 18,00,000
V0G →V2G	₹ 54,45,000	₹ 1,08,90,000	₹ 2,17,80,000
V1G →V2G	₹ 49,95,000	₹ 99,90,000	₹ 1,99,80,000
Incremental cost of charger procurement in INR			
Number of EVs	**10**	**20**	**40**
V0G → V1G	€ 5,280	€ 10,561	€ 21,122
V0G → V2G	€ 63,893	€ 1,27,787	€ 2,55,574
V1G → V2G	€ 58,613	€ 1,17,226	€ 2,34,452

Chapter 11. Conclusion and Way Forward for Enabling V2X in India

The study presented in this report analysed in detail the impact of EV integration on distribution systems, described various V2X applications, and analysed techno-economic aspects of various V2X applications supported by detailed case studies along with their cost- benefit analysis.

While the EV integration impact analysis provided insights into possible technical impacts that EVs can introduce into the distribution system, smart EV charging (V1G and V2G) demonstrated that such technical issues can be addressed by adopting to smart charging strategies. Moreover, the study also demonstrated V2G is far ahead of V1G technology in terms of the technical support, and the flexibility such as bidirectional charging features can bring to the table.

The study has analysed how V2G charging technology can provide tremendous reactive power support to the grid and to large customers, such as industry customers. The cost benefit analysis suggests that depending on the reactive power support, market regulations in place, and the extent of support required, reactive power support service from V2G can bring in commercial benefits to the customer, grid operator and other stakeholders. It was demonstrated through case studies that reactive power support from V2G DC chargers could improve low voltage issues in a distribution system. Different case studies were provided that showed the revenue earning potential of EVs by providing reactive power services. It was seen that both the DISCOM as well as large industrial/commercial customers could have significant value addition from this service.

V2G service for frequency support has been analysed in detail, establishing the technical capability and potential market revenue that can be generated by EVs while participating in frequency support services. Different combinations of parameters were cross-examined to determine the techno-economic viability of providing frequency regulation service.

The study also analysed how V2G services can be used not only in load shifting/peak demand reduction but they can also be used to maximise RE penetration. The optimisation framework has been used to analyse cost benefit aspects of the study.

V2H and V2B, as suggested by the study, have great potential to optimise the billing expenses of a household/building while providing a significant support. Techno-economic analysis under different scenarios demonstrated the potential benefit of V2H and V2B applications. In some scenarios, the high capital cost of bidirectional chargers may reduce the commercial viability of such services under current regulations. However, with AC V2G technology, the cost of V2G hardware is expected to be significantly reduced.

The other significant challenge in the deployment of EVs for bidirectional charging observed in this study is the relevant technical and commercial regulations. Although an EV may be technically capable of providing various grid services, this resource cannot be utilized to its full potential without relevant regulations.

11.1 Way Forward

Implementation of V2X in India has a lot of challenges and barriers across a wide range of verticals. So, enabling V2X in India would require concentrated efforts across the spectrum of EV stakeholders. It would only happen if each stakeholder understand the benefits of V2X and is willing to participate in V2X. To educate the stakeholders, extensive awareness programs are needed. This includes organizing webinars for the government, the standard issuing authorities, the regulators, grid operators, along with industry players from the automobile industry, energy management players, infrastructure builders etc. Further, the benefits of V2X need to be disseminated among the masses through social media platforms and ads in mass communication platforms like TV, newspaper and radio. Along with webinars and awareness programs, study tours to regions where V2X have been extensively studied such as the UK, California, Denmark etc., should be conducted. This would help the stakeholders in India to learn from the experience of the already completed pilots (see Figure 11:1).

National research labs on V2X need to be established at technical universities and research institutes to spearhead the study of V2X applications particularly in terms of the Indian ecosystem. In addition to research labs, the education of the technical workforce is equally important for testing and maintenance of the V2X ecosystem. So V2X labs at the technical and research institutes and polytechnic institutes should also be prioritized.

One of the primary responsibilities of the V2X labs is to design and conduct pilot studies on V2X. Different aspects, such as AC V2G, V2X services from medium and heavy-duty vehicles, various grid support services that can be enabled under the existing regulations, need to be studied in the V2X projects. The V2X labs need to be additionally augmented with standing working groups for the different aspects of VGI, such as grid integration working group, standard issuing working group etc. The learnings from the V2X projects need to be analysed by the working groups, and adequate steps can then be undertaken by the relevant authorities to increase the adoption of V2X in India.

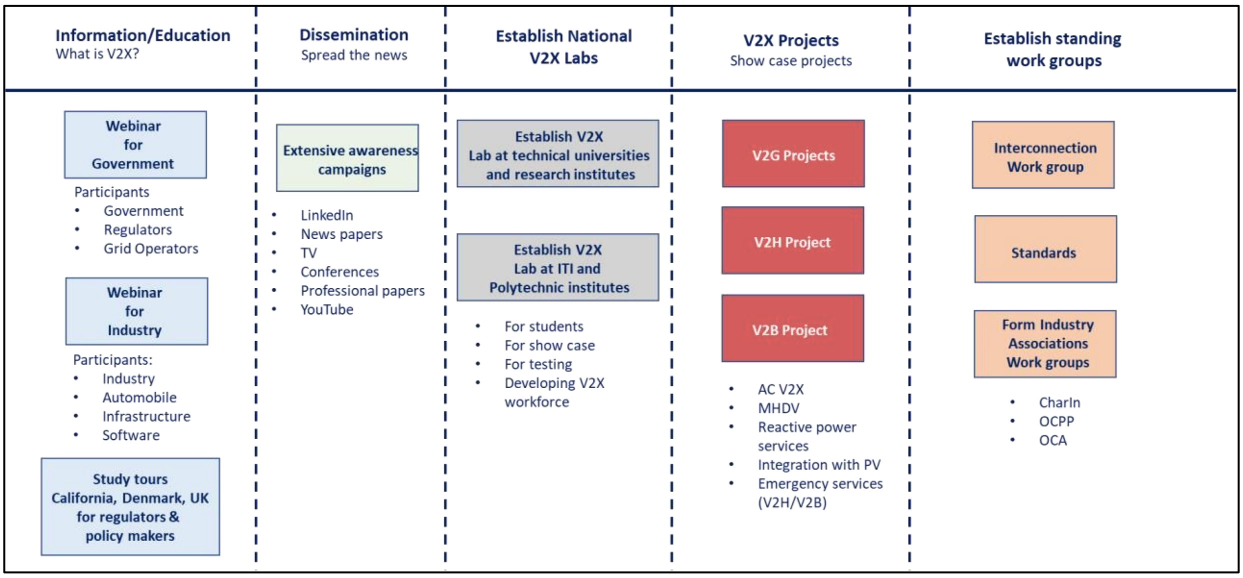

Figure 11:1: Proposed V2X action plan

Annexure

List of stakeholder consultations

- The Mobility House
- IoTecha
- Enel Group
- Fermata Energy
- CharIN e.V.
- CERC
- Dr. Indradip Mitra (GIZ)
- Ms. Sahana L. (GIZ)
- TATA Power
- BYPL

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.

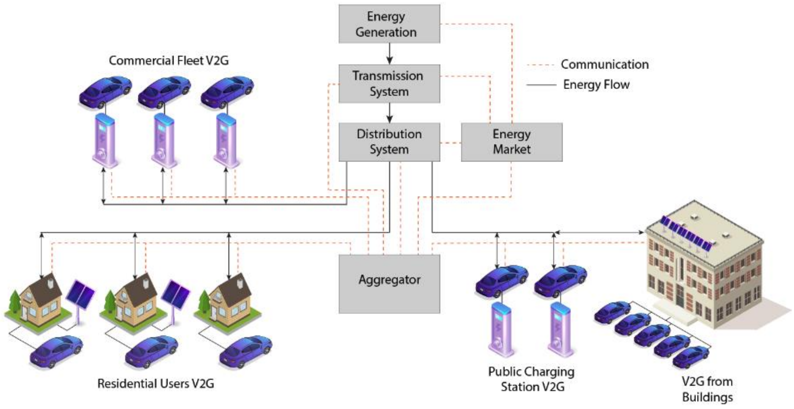

Figure A:1 V2G architecture

Figure A:2 V2H system[126]

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[126] 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/

GRID INTEGRATION LABORATORY
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

In cooperation with
Government of India
Ministry of Power
Central Electricity Authority

Address :
Indian Institute of Technology (IIT) Bombay
Powai, Mumbai - 400076
India

Authors:
Prof. Zakir H. Rather (IIT Bombay)
Mr. Angshu Plavan Nath (IIT Bombay)
Mr. Pratosh Patankar (IIT Bombay)
Mr. Desu Venkata Manikanta (IIT Bombay)

Contributors:
Shri Ashok Kumar Rajput (CEA)
Ms. Purvi Chandrakar (IIT Bombay)
Ms. Ruchi Kushwaha (IIT Bombay)
Next Dimension, California

Reviewers:
Mr. Bjoern Christensen (Next Dimension)
Grid Integration Lab team (IIT Bombay)

Designed by:
Ms. Ruchi Kushwaha (IIT Bombay)

Contacts :
Prof. Zakir H. Rather (IIT Bombay)
zakir.rather@iitb.ac.in
Mr. Angshu Plavan Nath (IIT Bombay)
194170008@iitb.ac.in
Ms. Ruchi Kushwaha (IIT Bombay)
22d0646@iitb.ac.in

Photo credits/sources:
IIT Bombay and Unsplash

Reach us at :
Email: iitbgil@gmail.com
GIL website: https://www.ese.iitb.ac.in/~gil/
GIL linkedin page : https://www.linkedin.com/company/grid-integration-lab-iit-bombay/

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