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In cooperation with

NITI Aayog

A CRITICAL REVIEW

SMART CHARGING STRATEGIES AND TECHNOLOGIES FOR ELECTRIC VEHICLES

Simulation-based study to evaluate the effects of E-mobility smart charging strategies

Led by Fraunhofer-Institute for Energy Economics and Energy System Technology IEE, Kassel

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Acknowledgement

This publication has been prepared by Fraunhofer-Institute for Energy Economics and Energy System Technology IEE, Kassel in collaboration with Indian Institute of Technology, Bombay (IITB), Technical University of Denmark (DTU), and Universidad Pontificia Comillas (IIT Comillas), and Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) India, as a part of the Nationally Determined Contributions – Transport Initiative for Asia (NDC-TIA) initiative. NDC-TIA is implemented by a consortium of seven organizations led by GIZ and funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under its International Climate Initiative (IKI).

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Disclaimer

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Abbreviations

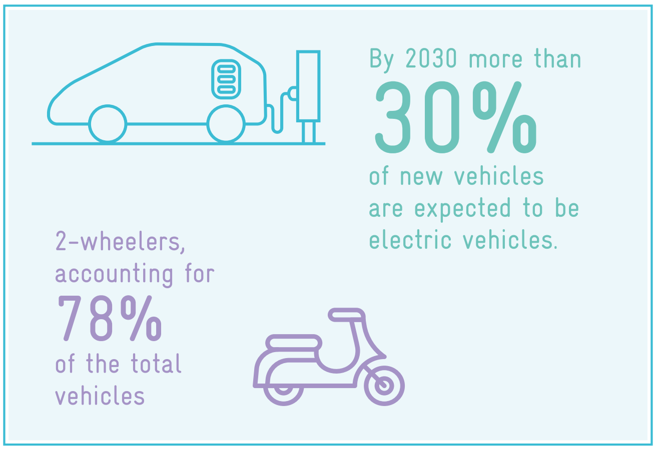
2W	Two-Wheeler
3W	Three-Wheeler
4W	Four-Wheeler
AC	Alternating Current
ADR	Automated Demand Response
AI	Artificial Intelligence
ANPC	Active Neutral Point Clamped
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BIS	Bureau of Indian Standards
BMS	Battery Management System
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CA	Certificate Authority
CCS	Combined Charging System
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
ChaDeMo	Charge de Move
CMS	Central Management System
CNA	Central Nodal Agency
CPO	Charge Point Operator
CPP	Critical Peak Price
CPU	Central Processing Unit
DAB	Dual Active Bridge
DC	Direct Current
DER	Distributed Energy Resources
DFEDR	Dynamic Feasible Energy Demand Region
DFFR	Dynamic firm frequency response
DHCP	Dynamic Host Configuration Protocol
DISCOM	Distribution Company / Operator
DL	Deep Learning
DNO	Distribution Network Operator
DPVFM	Dynamic Price Vector Formation Model
DR	Demand Response
DSO	Distribution System Operator
DST	Department of Science and Technology
DTU	Technical University Denmark
EMC	Electromagnetic Compatibility
eMIP	e-Mobility Inter-operation Protocol
EMS	Energy Management System
eMSP	Electric Mobility Service Provider
EO	Energy Operator
ESCOM	Energy Supply Company
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EVSS	EV Site Solution
FO	Fleet Operator
G2V	Grid-to-Vehicle
HAN	Home Area Network
HEMS	Home Energy Management System
HT	High Tension
IC-CPD	In-cable control and protection device
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineer
IKI	International Climate Initiative
ISO	International Organization for standardization
ITF	International Transport Forum
kVA/kVAh	kilovolt-ampere/kilovolt-ampere hour
kW/kWh	Kilowatt/kilowatt-hour
LAN	Local Area Network
LT	Low Tension
LVRT	Low-Voltage-Ride-Through
MDP	Mixed Discrete Programming
MILP	Mixed-Integer Linear Programming
ML	Machine Learning
MoP	Ministry of Power
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NDC-TIA	Nationally Determined Contribution – Transport Initiative for Asia
NP	Non-deterministic Polynomial Time
OCHP	Open Clearing House Protocol
OCPI	Open Charge Point Interface
OCPP	Open Charge Point Protocol
OEMs	Original Equipment Manufacturers

OICP	Open Inter-charge Protocol
OLEV	Office for Low Emission Vehicles
OSCP	Open Smart Charging Protocol
P2P	Point to Point
PCS	Public Charging Station
PEV	Plug-in Electric Vehicle
PFC	Power Factor Correction
PLC	Power Line Carrier
POSOCO	Power System Operation Corporation Limited
PRC	Parallel Resonant Converter
PTR	Peak Time Rebate
PV	Photovoltaic
RCD	Residual Current Device
RE	Renewable Energy
REEV	Range Extended Electric Vehicle
RFID	Radio-frequency identification
RIW	Random-in-Window
RIW-FR/RIW-VR	Random-in-Window-Fixed charging rate/ Random-in-Window- Variable charging rate
RTP	Real-Time Price
SA	Sub Aggregator
SAE	Society of Automotive Engineers International
SERC	State Electricity Regulatory Commission
SFFR	Static Firm Frequency Response
SiC	Silicon Carbide
SLDC	State Load Dispatch Centre
SMERC	Smart Grid Energy Research Centre
SMGW	Smart Meter Gateway
SNA	State Nodal Agency
SOC	State of Charge
SPRC	Series-Parallel Resonant Converter
SRC	Series Resonant Converter
TCP	Transmission Control Protocol
TNPC	T-Type Neutral Point Clamped
TOU	Time of Use
V2B	Vehicle-to-Building
V2D	Vehicle-to-Device
V2G	Vehicle-to-Grid
V2GTP	Vehicle to Grid Transport Protocol
V2H	Vehicle-to-Home
V2V	Vehicle-to-Vehicle
WPD	Western Power Distribution
WPT	Wireless Power Transfer
WRI	World Resources Institute
XML	Extensible Markup Language
ZCS	Zero Current Switching
ZVS	Zero Voltage Switching

01

Introduction: Review of Smart Charging Strategies and technologies

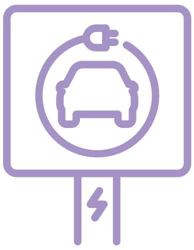
Electric Vehicles (EVs) are being rapidly integrated into the energy systems of many countries to reduce carbon emission from the mobility sector to help address the climatic issues, with ambitious goals of EV targets set at national/regional levels. More specifically, the push for EVs is driven by the global climate agenda established under the Paris Agreement to reduce carbon emissions across the world to address the growing global warming issue. Importantly, not only would a switch from combustion-engine vehicles to EVs lead to lower emissions, but EVs also create a lot less local air pollution. In addition, the deployment of EVs is also driven by national agendas to reduce oil demand and dependence on oil imports, and encouragement of a local EV manufacturing industry for job creation. On the other hand, EVs through several grid support services, are expected to support the grid, and help in accommodating higher renewable energy penetration while maintaining secure and stable grid operation. However, for an effective, efficient, economical, and reliable EV integration, a coordinated and optimal approach is required, considering all the relevant technical, policy and regulatory issues. EVs under an uncoordinated control strategy can introduce a range of challenges viz. increase in peak load, power line congestion, stressing power system equipment, and requirement of upgradation and reconfiguration. Hence, increasing EV adoption necessitates smart charging of the EV loads (Global EV Outlook 2020).



The registered number for electric vehicles in India is around 873,301 according to Government of India's Vahan database as on 30 November 2021. By 2030 more than 30% of new vehicles are expected to be electric vehicles (Global EV Outlook 2020). India has over 250 million vehicles, and this fleet is dominated by 2-wheelers, accounting for around 78% of the total vehicles (Bhagwat et al., 2019). Amongst the different vehicle segments, public buses, taxi fleets, 2-wheelers, and three-wheelers are expected to be the first adopters of EVs. As the country is at an early stage of EV deployment, public charging infrastructure is still limited, however, expected to grow fast owing to EV integration target. In this regard, the Ministry of Power (MoP) has already identified nine major cities and twelve intercity routes as pilots to enable EV charging infrastructure. Similarly, several states have also started introducing policies to promote EV adoption and charging infrastructure deployment. Currently (as of September 2021) 21 states of India have final (18) or draft (3) EV policies in place.

The rapid growth in EV uptake required to achieve EV deployment targets of India will have to address two major challenges. The first challenge is ensuring the deployment of adequate charging infrastructure required to serve the needs of the growing number of EVs. The second challenge is the integration of the EVs into the power system in secure and stable manner. However, to accommodate higher EV penetration with least possible grid upgradation cost implications, smart charging will play a key role not only in managing high share of EVs, but also cater to a range of grid support services. Therefore, smart charging of EVs is necessary to effectively manage the charging demand with the available grid infrastructure and generation capabilities. Smart charging will play a crucial role in talking various goals, such as cost minimization, network loss minimization, congestion management, grid support and grid stability. The success of the EV revolution hinges primarily on the timely deployment of effective EV charging infrastructure and smart charging strategies. However, at the same time, EV adoption is the main driver for the business case of EV charging infrastructure. Technical solutions for smart charging strategies, and policy and regulation matters, informed by a thorough understanding of the EV charging ecosystem, can offer solutions to this problem.

The rapid growth in EV uptake required to achieve EV deployment targets of India will have to address two major challenges. The first challenge is ensuring the deployment of adequate charging infrastructure required to serve the needs of the growing number of EVs. The second challenge is the integration of the EVs into the power system in secure and stable manner.



Although the e-mobility plan is developed at the central level, the onus largely lies on the state and union territory governments, which must develop and implement relevant policies, schemes and regulatory frameworks to enable the adoption of EVs and deployment of charging infrastructure in their respective states. Thus, considering India's federal structure as well as the wide variance in the social-geographic and economic variances between states, a one-size fits all approach cannot be applied. The development of adequate charging and power system infrastructure to support the up-take of EVs would rest upon state-specific policy, regulatory measures, and effective implementation of such policy and regulatory interventions. Therefore, this study is focussed on global and national review of smart charging strategies, smart charging technology, pricing mechanism, consumer behaviour, and simulation based critical analysis of smart charging strategies with the main focus on the Indian EV ecosystem. The global review and the simulation-based studies will be used to derive comprehensive guidelines for adoption of smart charging strategies, policy and regulatory interventions, pricing mechanisms, fiscal and non-fiscal incentives, and consumer behaviour for Indian scenario that could be used by policymakers, regulators, Distribution Companies (DISCOMs), transmission system operators, OEMs, fleet operators, and other players in EV industry in India for effective and reliable integration of EVs with the existing grid.

1.1 About this Study

The Nationally Determined Contributions – Transport Initiative for Asia (NDC-TIA) is a regional initiative funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). It is a joint

EVs through several grid support services, are expected to support the grid, and help in accommodating higher renewable energy penetration while maintaining secure and stable grid operation.

project of seven organizations and with the engagement of China, India, and Vietnam. The organizations partnering with Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) on this project are World Resources Institute (WRI), International Council on Clean Transportation (ICCT), International Transport Forum (ITF), Agora Verkehrswende, Renewable Energy Policy Network for the 21st Century (REN21), and the Partnership on Sustainable, Low Carbon Transport (SLoCaT). For the India component of the project, the implementing partner is the National Institution for Transforming India (NITI Aayog).

Under the NDC-TIA India Component, the project "**Simulation-based study to evaluate the effects of E-mobility smart charging strategies**" is focused on relevant smart coordinated charging strategies that will need to be adopted in different scenarios and conditions in India. This project is carried out by consortium led by Fraunhofer Institute for Energy Economics and Energy System Technology IEE, Kassel (IEE) in collaboration with Indian Institute of Technology, Bombay (IITB), Technical University Denmark (DTU), and Universidad Pontificia Comillas (IIT Comillas).

This specific study focuses on EV smart charging strategies and approaches, related policy and regulatory measures, technical aspects, grid integration of EVs, and the way forward for smooth EV adaption in the Indian EV ecosystem. The study will use real life data to develop models of distribution feeders in India, implement charging and coordination algorithms using a robust open source simulation environment. The results of the analyses will act as a strong base in identifying gaps and refining scope of work for adoption of smart charging approaches at each necessary level/node of the EV ecosystem. The study based on a combination of desk research, simulation, regular workshops with the selected DISCOM(s), consultations with stakeholders, will be used to identify and recommend various smart charging interventions and guidelines that can be adopted for the use by regulators, policy makers, DISCOMs, and other stakeholders, and later adopted state-wide.

1.2 Aim of the Study

The project aims to conduct a high-quality simulation supported study on smart charging strategies (unidirectional power flow) with high impact/quality reports that can be used by the Government of India including State Governments, distribution system operators/ companies (DISCOMS), transmission system operators (POSOCO, SLDCs), planning and regulatory agencies (Central Electricity Authority (CEA), Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERCs)) and other stakeholders (EV industry etc.) to frame, adapt, and/or revise policies, regulations for smart charging strategies for EVs and their integration with distribution grid. Secondly, it focuses on improvement of the overall environment (technical, policy, regulatory) related to EV charging infrastructure, smart charging strategies, and consumer response.

The success of the EV revolution hinges primarily on the timely deployment of effective EV charging infrastructure and smart charging strategies

1.3 Objectives of the Study

This project conducts a detailed study based on critical global review on smart charging strategies, and simulation studies on an identified DISCOM network with a major thrust on the following focus points:

- A detailed and comprehensive global review of different smart charging strategies and coordination approaches for EV charging
- Structured framework for desired data collection from selected DISCOM(s) and other relevant sources along with data filtering and quality check
- Performing concrete simulations on smart charging strategies for EVs while considering different scenarios/use cases with the grid data provided by the DISCOM(s)
- Preparation of comprehensive and concrete guidelines for smart EV charging in India
- Conducting a detailed literature review on charging infrastructure and consumer response

1.4 About this Report

A holistic framework will be developed to select key strategies for modelling the situations under a simulation environment leading to concrete recommendations for the stakeholders

This report is the first in the series of the overall study – "**Simulation-based study to evaluate the effects of E-mobility smart charging strategies**" outlining the concept of smart charging, smart charging technologies and related products & solutions, gaps in Indian regulations and policies from smart charging perspective, commercially available smart charging products and equipment, and case studies in the form of existing smart charging projects under Part A of the report. Part B of this report is dedicated to an exhaustive and critical review of various smart charging strategies and approaches.

This report sets the main context for the core objective of the overall project, which is to identify relevant smart charging and coordination strategies, appropriate policy and regulatory interventions, and way forward for seamless adoption of smart charging in Indian EV ecosystem. A holistic framework will be developed to select key strategies for modelling different scenarios under a simulation environment leading to concrete recommendations for the stakeholders. Moreover, chapter 3 of this report provides a comprehensive overview of smart charging technologies, smart chargers and related products, equipment, and commercially available chargers (along with specifications) in India, which can be useful for a wide set of stakeholders in the EV industry. Further, chapter 4 of this report provides a bird's eye view about the smart charging scenario in India including incentives, gaps, and practical challenges. Lastly, a number of case studies / projects in smart EV charging are given in section 3.11 of chapter 3 to give a better understanding to the stakeholders about implementation of smart charging in Indian EV ecosystem.

02
Smart Charging of Electric Vehicles

Smart charging of EVs refers to an optimal or intelligent charging of electric vehicles which adapts to the conditions of the electricity grid and the needs of EV users. This intelligent or optimal charging of an EV in principle implies efficient use and management of energy available in a certain time period. Features include control of rate/speed and time of charging for peak shaving, monitoring real time data to ensure demand side management, smooth integration with distribution grid, identification for smart charging stations in vicinity of an EV user, etc. In order to explore smart charging in detail and appreciate the need for and benefits of smart charging, it is important to understand the simplest way of charging known as "dumb charging" and several challenges associated with it.

2.1 Challenges with dumb charging

Refuelling an electric vehicle by recharging its battery using uncontrolled conventional charging practices is termed as "dumb charging". However, high penetration of EVs under dumb charging mode introduces a range of issues in the grid, thus impacting the grid operation and limiting EV hosting capacity of the distribution feeders, and necessitating grid upgradation. Such issues include overloading of/congestion in distribution feeder, power quality issues, voltage dip, unbalanced operation, and increased losses. For example, EV charging driven high peak loading issue initiate a new challenge of maintaining generation-demand balance during peak loading time, which necessitates scheduling of expensive generators and the requirement of installation of new generation plants. Therefore, high peak loading issue is not economically and environmentally viable due to its cost implications, and at the same time conventional generation sources are primarily filling the requirement of providing the additional power. Bringing in additional conventional generators to meat peak demand will negate the very reason (carbon emission reduction) for shifting mobility to electric vehicles.

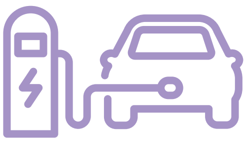
Refuelling an electric vehicle by recharging its battery using uncontrolled conventional charging practices is termed as "dumb charging"

Uncontrolled charging of EVs draws high power, which results in network overloading conditions. Network overloading includes overloading of equipment, faster aging of devices leading to frequent occurrence of faults and in extreme case may lead to system instability. Equipment stressing and faster aging results into requirement of major upgradation and reconfiguration. Therefore, to address the above mentioned limitations of dumb charging, smart charging can be utilised to optimally and intelligently charge EVs in a coordinated and controlled manner.

Smart charging not only mitigates the limitations of dumb charging, but it can also facilitate maximising the utilization of renewable generations, provided ancillary services support and backup storage. The objective of smart charging varies according to stakeholders and their requirements. Overall system cost minimization, load levelling and valley filling, maximization of RE utilization, and providing grid support services are the major objectives of a system operator. Minimisation of charging cost, maximization of satisfaction factor, and load levelling are the common objectives from EV owner's perspective. Smart charging is performed using different strategies, which are the combination of information flow and decision taking ability between aggregator and EV owner. Based on the information flow and decision making, smart charging is categorized into different strategies and coordination approaches, which are described in detail under Part B of this report.

2.2 Key stakeholders involved in smart charging

In smart charging, EV battery is charged considering all the decision parameters of the system and requirements of EV owner. An external entity or a person controls the charging and decides the schedule of charging complying the interests of EV owner and other stakeholders. In other words, smart charging is an action of externally controlling the EV charging for predefined objectives and constraints. As smart charging is externally controlled, it requires observability and communication between the entities. Since it will be practically challenging for a grid operator to monitor , manage and control all the EVs, EV aggregators act as interface between EVs and the grid operator. Roles of key stakeholders in smart charging adoption are mentioned below in detail.



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2.2.1 GRID OPERATOR

Grid operator represents Distribution Network Operator (DNO) or Distribution System Operator (DSO) or Distribution Company (DISCOM) of a particular network. Grid operators are responsible for maintaining the continuity of electric supply. They control the power grid via communication within and neighbouring utilities. They are also responsible for restoring the supply in case of failure due to any natural disaster or fault conditions. Due to this reason, system operators are interested to maintain secure and stable grid operation.

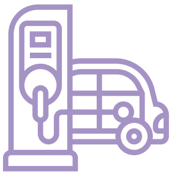
2.2.2 EV OWNER

EV owner is a proprietor of EV who is responsible for taking the EV charging decisions. In EV smart charging study EV driver can also be address as EV owner because of having charging decision rights in some situations. The main objective of an EV owner/user is reduced cost of charging while meeting its commuting needs.

Smart charging not only mitigates the limitations of dumb charging, but it can also facilitate maximising the utilization of renewable generations, provided ancillary services support and backup storage.

2.2.3 AGGREGATOR

EV aggregator is a third party between energy supplier i.e., system operator and energy consumer i.e., EV user/owner. In other words, it establishes an indirect connection by coordinating with EV and system operator by acting as a middle entity between EV owner and system operator. It cooperates with the stakeholders to fulfil their demand (or supply) requirements while respecting the supply (or demand) capability of another stakeholder. It collects information from both (viz, system operator and EV owner) and take suitable decision on EV charging considering the request and constraint from both the parties. From economic aspects aggregator gets financial returns from both stakeholders for providing the service and ease the charging process.



2.3 Potential Benefit of Smart Charging

2.3.1 POTENTIAL BENEFIT TO ELECTRIC GRID

Smart charging maintains the system parameters within the permissible limit while ensuring reliable supply to the customer. Some of the benefits of smart charging to the grid operator are mentioned below:

1. **System stability and reliability**

   Smart charging maintains the grid stability by directly or indirectly managing the charging behaviour of EV load. Directly managing charging covers centralised decision taking strategies, whereas indirectly managing charging demand covers decentralised and distributed decision taking strategies. Moreover, hierarchical decision taking strategy also ensure grid stability by managing the charging load with combination of centralised and decentralised decision.

2. **Reduce grid upgradation requirement**

   Smart charging through a coordinated manner can facilitate charging of more EVs compared to dumb/uncontrolled/uncoordinated charging, thereby effectively increasing EV hosting capacity of a distribution feeder. More importantly, at peak load condition, smart charging will not only be able to limit the peak load, but it can also help in peak shaving, hence reducing the need for grid upgradation.

3. **Increased RE integration and reduced carbon emission**

   Grid with high percentage of generation mix from conventional generators are benefited in terms of carbon emission reduction as smart charging reduces the additional generation scheduling and encourages utilisation of renewable energy. Moreover, through smart charging, EVs can provide grid support services and help in accommodating higher RE penetration

4. **Reduces overall cost of the system**

   Since Smart charging reduces the additional generation and infrastructure requirement, and thereby reduces the cost associated with additional expensive generators and establishing new infrastructure.

2.3.2 POTENTIAL BENEFIT TO EV OWNER

EV owners benefit in terms of reduced charging cost and reliable electrical supply as a result of smart charging of EVs. In addition, EV owners indirectly are benefited through clean air and healthy environment because of low demand of additional generation and better utilisation of renewable energy generation.

2.3.3 POTENTIAL BENEFIT TO CHARGING STATION OPERATOR

Charging station owner/operator earns financial revenue from smart charging by providing the charging management services to EV owners and grid operators. In addition, electricity price hike at peak hour window and peak load duration generates an additional profit for the charging station owner/operator.

The broader landscape of smart charging benefits are shown in Figure 1.

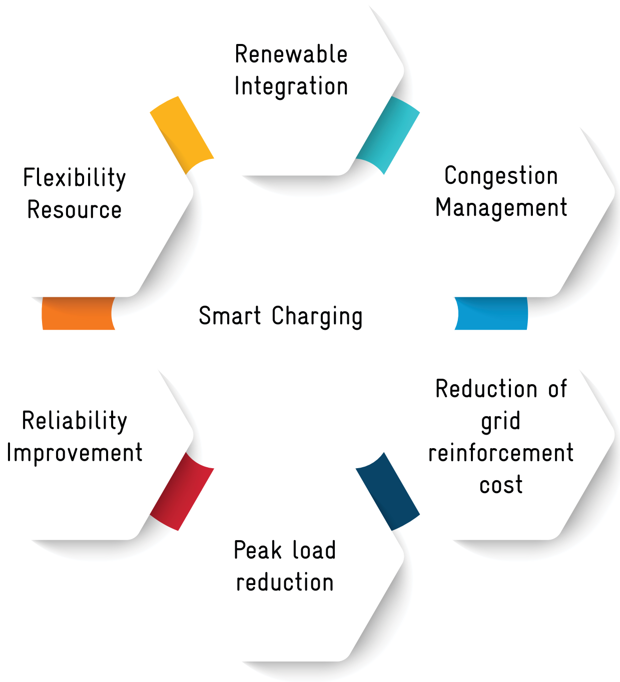
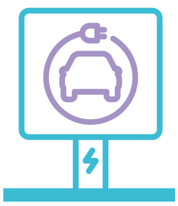


Figure 1: Usefulness of smart charging

Some of the key factors that can enable deployment of smart charging include but not limited to:

(a) Charging infrastructure
(b) Defining clear roles and responsibilities of stakeholders
(c) Designing or strengthening regulations and policies
(d) Enabling Information and Communications Technology (ICT) control and communication protocols
(e) Strengthening the role of aggregators and system operators
(f) Research and development in advancements in smart charging technologies



Smart charging in electric vehicle infrastructure in India is crucial from various perspectives, especially to manage EV load.

2.4 Levels of Smart Charging

The simplest form of incentive, which is generally termed as **time-of-use pricing**, encourages consumers to move their charging from peak to off-peak periods. More advanced smart charging approaches, such as **direct control** mechanisms, will be necessary as a long-term solution at higher penetration levels and for the delivery of close-to-real-time balancing and ancillary services. Such mechanisms range from simply switching on and off the charging, to **unidirectional control of vehicles (V1G)** that allows for increasing or decreasing the rate of charging, to the technically challenging **bidirectional vehicle-to-grid (V2G),** which allows the EV to provide services to the grid in the discharge mode. In addition, **vehicle-to-home (V2H) and vehicle-to-building (V2B)** are forms of bidirectional charging where EVs are used as a residential back-up power supply during periods of power outage or for increasing self-consumption of energy produced on-site (demand charge avoidance). Further advanced level of charging would be with dynamic pricing and automated control, which is difficult to materialise without the support of policymakers and regulators. (Source: IRENA Innovation Outlook: Smart charging for electric vehicles, 2019)

Advanced smart charging approaches, such as direct control mechanisms, will be necessary as a long-term solution at higher penetration levels and for the delivery of close-to-real-time balancing and ancillary services.

AC charging stations typically offer a charging power of up to 22 kW, in individual cases up to a maximum of 44 kW. DC charging stations are typically used for fast charging (50 – 150 kW) and superfast charging with higher outputs of up to 400kW.

03

Smart Charging Technologies

Electric vehicle charging systems are one of the key components in smart charging. The converters can perform unidirectional and bidirectional power flow and provide reactive power for smart charging through controlled switching. Communication interfaces, connectors, and standards are essential to realise smart charging functions and are therefore discussed in the report.

3.1 Charger types and description of technologies for EV charging

The first distinction of EV charging technology is the distinction between conductive charging using cables and inductive charging which enables wireless energy transfer. Figure 2 shows the basic charging options and the typical charging capacities of conductive charging (alternating current (AC) and direct current (DC) charging) and inductive charging.

AC charging stations typically offer a charging power of up to 22 kW, and in special cases, a maximum of 44 kW. DC charging stations are typically used for fast charging (50 – 150 kW) and superfast charging with higher outputs of up to 400 kW and higher capacity. Furthermore, DC systems come into consideration in the area of normal charging in the future.

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DC charging stations are typically used for fast charging (50 – 150 kW) and superfast charging with higher outputs of up to 400 kW and higher capacity

In the European Union (EU), charging power levels are divided into three categories: normal charging with up to 22kW charging power, fast charging with up to 150 kW, and super-fast charging with up to 400kW (VDE et al. 2020). Other charging categories can be administered depending on the region and applied standard. An overview of charging technology and power levels is given in (Habib et al. 2020).

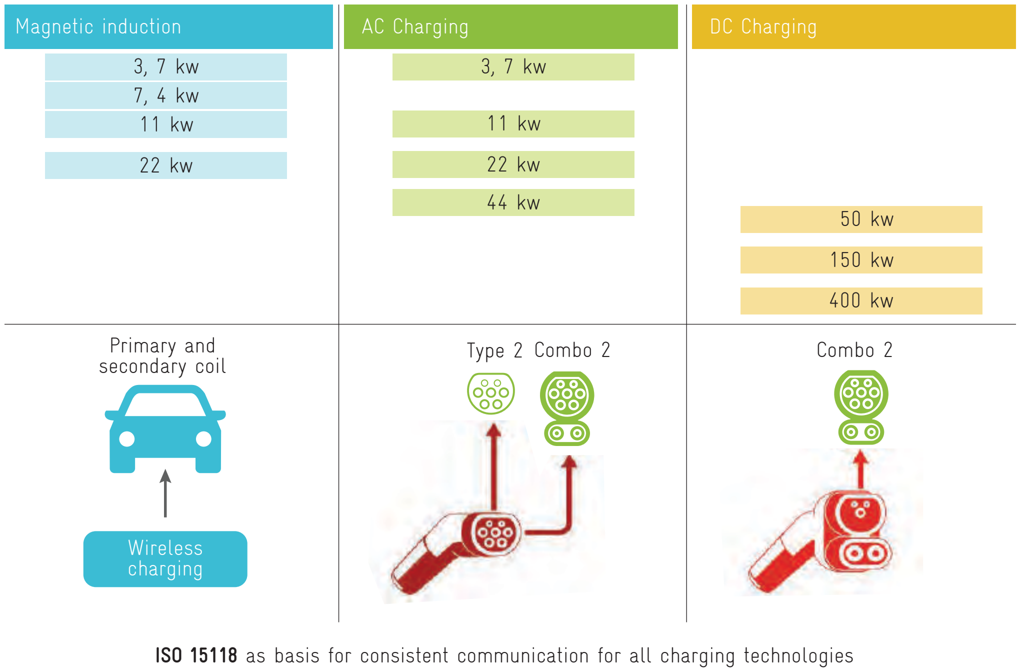


Figure 2: Overview of the charging options and their typical charging capacities (Nationale Plattform Elektromobilität)

Conductive charging systems are further classified into four charging modes according to the IEC61851-1 standard, of which modes 2 to 4 are intended for passenger cars and commercial vehicles:

Installing the power electronics in the vehicle results in stricter limits for weight and volume, which limits the charging power of an AC charging system.

- Charging mode 2 describes charging at household and industrial sockets with a control and communication device in the cable.
- Charging mode 3 describes single-phase or three-phase charging with alternating current (AC) using a permanently installed charging station.
- Charging mode 4 describes charging with direct current (DC) at permanently installed charging stations.

Depending on the application (home charging, public charging, etc.), various communication options (see section 3.4 Communication protocols) and user interfaces are available for use. Charging stations usually indicate the status of the charging process with an illuminated indicator or display. Radio-frequency identification (RFID) technology is a common standard for access control. More sophisticated and expensive systems provide notifications and control of the charging plan and process via mobile phone apps. The vehicle usually provides information about the charging process via its infotainment system as well.

3.1.1 CONDUCTIVE CHARGING – AC AND DC CHARGING SYSTEMS

In this section a high level comparison of AC and DC charging systems is realized. More detailed explanations on circuit and component level are given in section 3.5 Power Electronics.

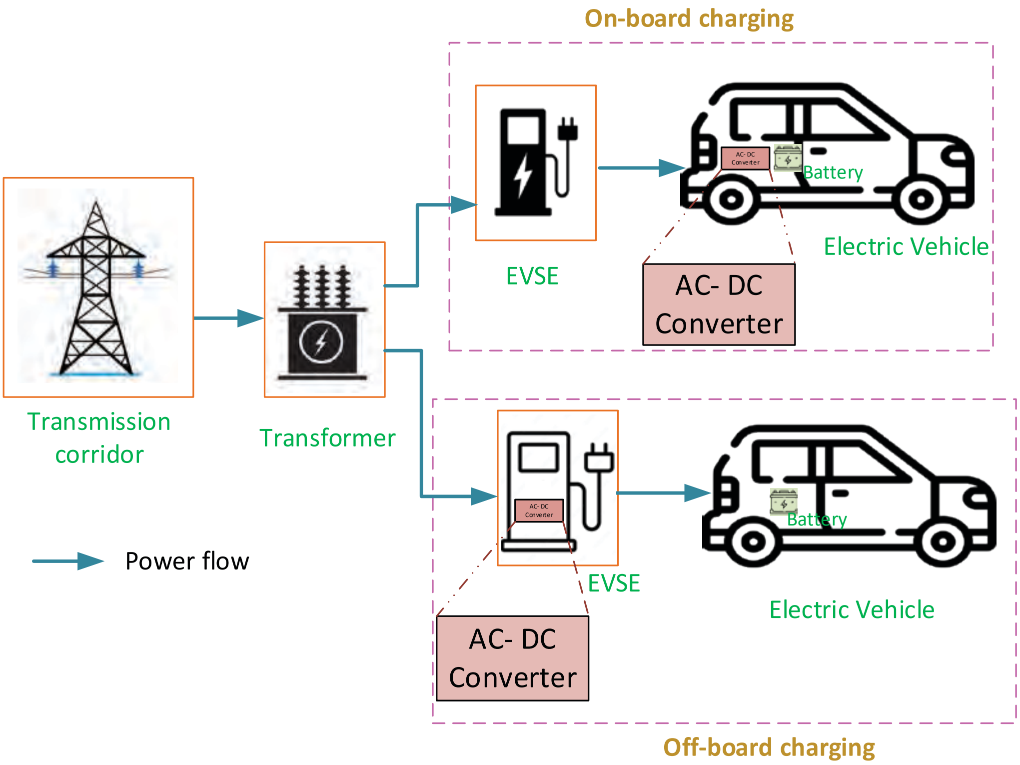


Figure 3 : AC and DC conductive charging ecosystem

The main distinguishing feature between AC and DC charging technology (as shown in Figure 4 - Figure 6) is the location of power electronics, which could be either within the charging station (so-called Wallbox) or within the vehicle (Onboard Charger) and therefore the energy transfer from the station to the vehicle is either through DC or AC current. Accordingly, it is necessary to distinguish between the components onboard the vehicle and in the Electric Vehicle Supply Equipment (EVSE).

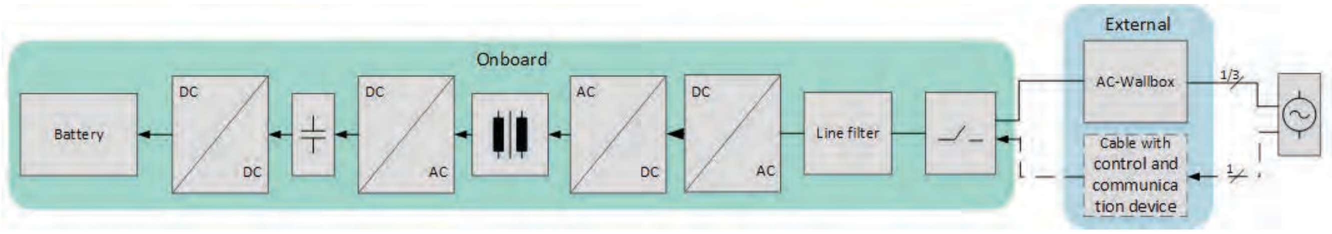


Figure 4: Block diagram of a galvanic isolated AC charging system

Installing the power electronics in the vehicle results in stricter limits for weight and volume, which limits the charging power of an AC charging system. Therefore, AC charging systems are commonly used for normal charging systems (up to 22kW). The main part of the hardware cost is derivative of the onboard part of the system, which transfers the cost of the charging system from the infrastructure (as external devices) into the vehicle. Today, the investment cost for AC charging systems is much lower than for DC charging systems in an identical power class, likely due to economies of scale and availability or demand (Maur et al. 2020; Bünger et al. 2019), but may decrease in the future. A major advantage of an AC charger is that charging without an additional charging station is possible (charging mode 2). Another advantage is that the charger can be integrated into the already existing engine or battery cooling system without a dedicated cooling system. In addition, an onboard charger is required for Vehicle to Vehicle (V2V) and Vehicle to Device (V2D) functionalities.

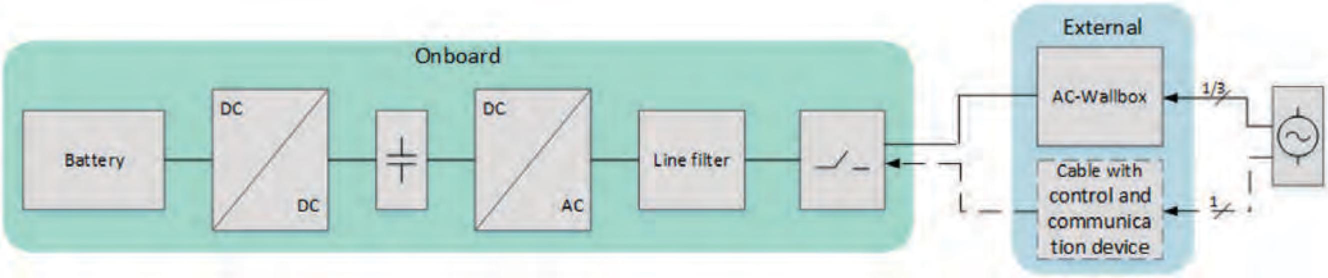


Figure 5: Block diagram of an AC charging system without galvanic isolation

Today, most AC chargers have galvanic isolation, but it is possible to design an AC charger without galvanic isolation, as shown in Figure 5.

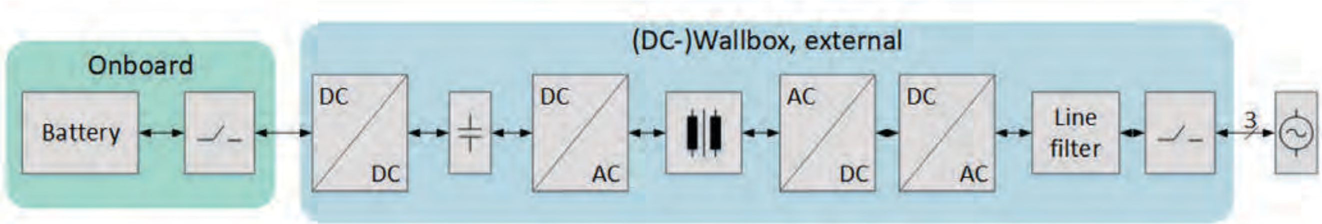


Figure 6: Block diagram of a galvanic isolated DC charging system

Contrary to AC chargers, DC chargers are not limited by weight or volume, resulting in their fast charging application. Current DC fast and super-fast chargers feature up to 400 kW in output power and will reach higher limits in the future. The weight and installation space requirements of a DC charging system onboard the vehicle are significantly lower than an AC system. On the other hand, the DC charging system requires a cooling system and cannot benefit from the vehicle cooling system.

Today, AC and DC charging systems are used in parallel. For fast charging, only DC chargers come into question. However, for normal charging it is not foreseeable whether AC or DC charging will be the dominating technology for conductive charging in the future.

3.1.2 OTHER CHARGING TECHNOLOGIES

DC charging system requires its own cooling system and cannot benefit from the vehicle cooling system.

Battery supported / mobile charging stations: One option is to integrate batteries into charging stations to support the charging of traction batteries onboard the vehicle. Battery supported charging stations may be grid independent and can substitute existing grid connected infrastructure during peak demand, at locations with weak grid connectivity, or cultural events with a temporary charging demand (Hebermehl 2019; ads-tec Holding GmbH).

Pantographs - Heavy Duty / Bus charging: It is possible to use a pantograph system for charging buses or heavy-duty trucks, as shown in Figure 7. There are two potential charging options for heavy duty vehicles: First, the installation of overhead lines on highways and other roads to directly supply electrical energy to the drive train and battery (Jong 2020), or second, the installation of pantograph charging stations at appropriate locations, e.g., at the terminus of bus lines or depots (ABB; Hasselmann 27.08.20).

Figure 7: Pantograph charging (Volvo Buses 2016)

Inductive charging: A convenient way of charging EVs is inductive charging. The issue with inductive charging is the limited power of about 20 kW and the high losses of around 10% (VDE et al. 2020). The area of the receiving plate on the EV affects the charging speed, so it is preferable to have a large area on the charging plates, and needs to be considered, especially for two-wheelers.

Inductive charging systems can be stationary or dynamic. Stationary systems can only be utilized in parking lots and garages or during stops e.g., at traffic signals, whereas dynamic systems allow battery charging while the vehicle is in motion. The advantages of wireless charging are:

- aesthetic quality, cable-less charging,
- reliability, durability,
- user-friendliness

Drawbacks and challenges are:

- electromagnetic compatibility (EMC) issues,
- limited power transfer, lower efficiency,
- bulky and expensive structures

Inductive chargers are not broadly commercialized and employed as conductive ones.

Automatic conductive charging is as convenient as inductive charging but is not limited to power. It is possible to use an automated system (e.g. robot) to plug in a standard charging connector like a human or to insert a charging connector into the ground that functions similar to a pantograph (Continental Engineering Services).

Battery swapping is one way to avoid long charging stops for the customer. The only commercially available system today is realized by NIO Power Swap (NIO 2020). Battery swapping is a good option for two-wheelers like e-bikes, motor scooters or other light utility vehicles (Swobbee).

3.2 Connectors

Connectors designed specifically for Battery Electric Vehicle (BEV) charging can be categorized into AC- and DC- charging connectors. Figure 8 - Figure 11 show the pin layout of various connectors.

3.2.1 AC-CHARGING CONNECTORS

Figure 8: **Type 1 AC charging connector**

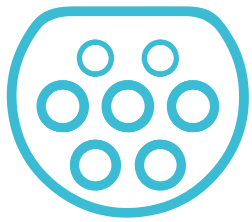


Figure 9: **Type 2 AC charging connector**

Type 1: Single phase charging with an output power of up to 7.4 kW (230V, 32A). Mainly used in North America and Asia, shown in Figure 8.

Type 2: Single or three phase charging with output power of up to 43 kW (230/400 V, 63A), shown in Figure 9. European AC-charging standard connector, is also used in China with the swapped positions of plug and socket.

3.2.2 DC-CHARGING CONNECTORS

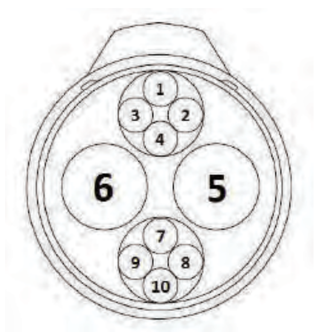


Figure 10: **ChaDeMo DC charging connector**

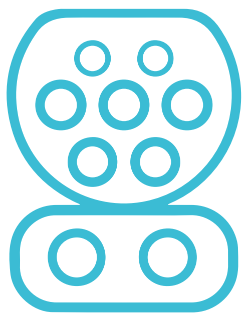


Figure 11: **CCS-Combo 2 DC charging connector**

ChaDeMo: Japanese standard which supports up to 400kW (1000V) output power today. It is suitable for 400V and 800V battery systems and is given in Figure 10.

CCS-Combo 1/2: Combines type 1 or 2 sockets with two additional pins for DC charging, as shown in Figure 11. Supports output power of up to 350 kW with an output voltage range of 400 to 950 V. Mainly used in Europe and North America.

3.2.3 FUTURE DEVELOPMENT / OUTLOOK

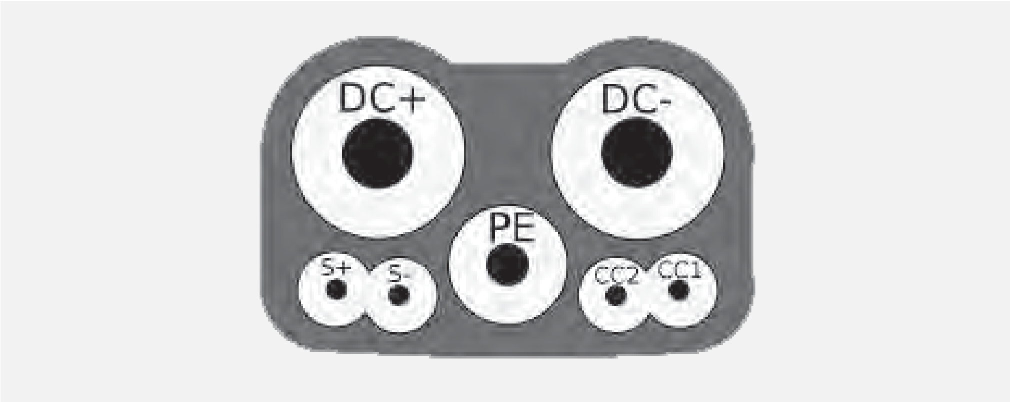


Figure 12: Chaoji connector for high power DC charging

Chaoji/ChaDeMo 3.0: Chinese/Japanese cooperation for a new connector type (Figure 12) with up to 900kW output power under the GB/T and ChaDeMo standard announced in April 2020 (CHAdeMO Association 24.04.20).

CCS Megawatt charging: The CharIN association is working on the implementation of a connector for MW charging of trucks and busses which supports up to 3 MW output power (CharIN e. V. 13.10.20; Randall 11.7.19).

3.3 Relevant Standards

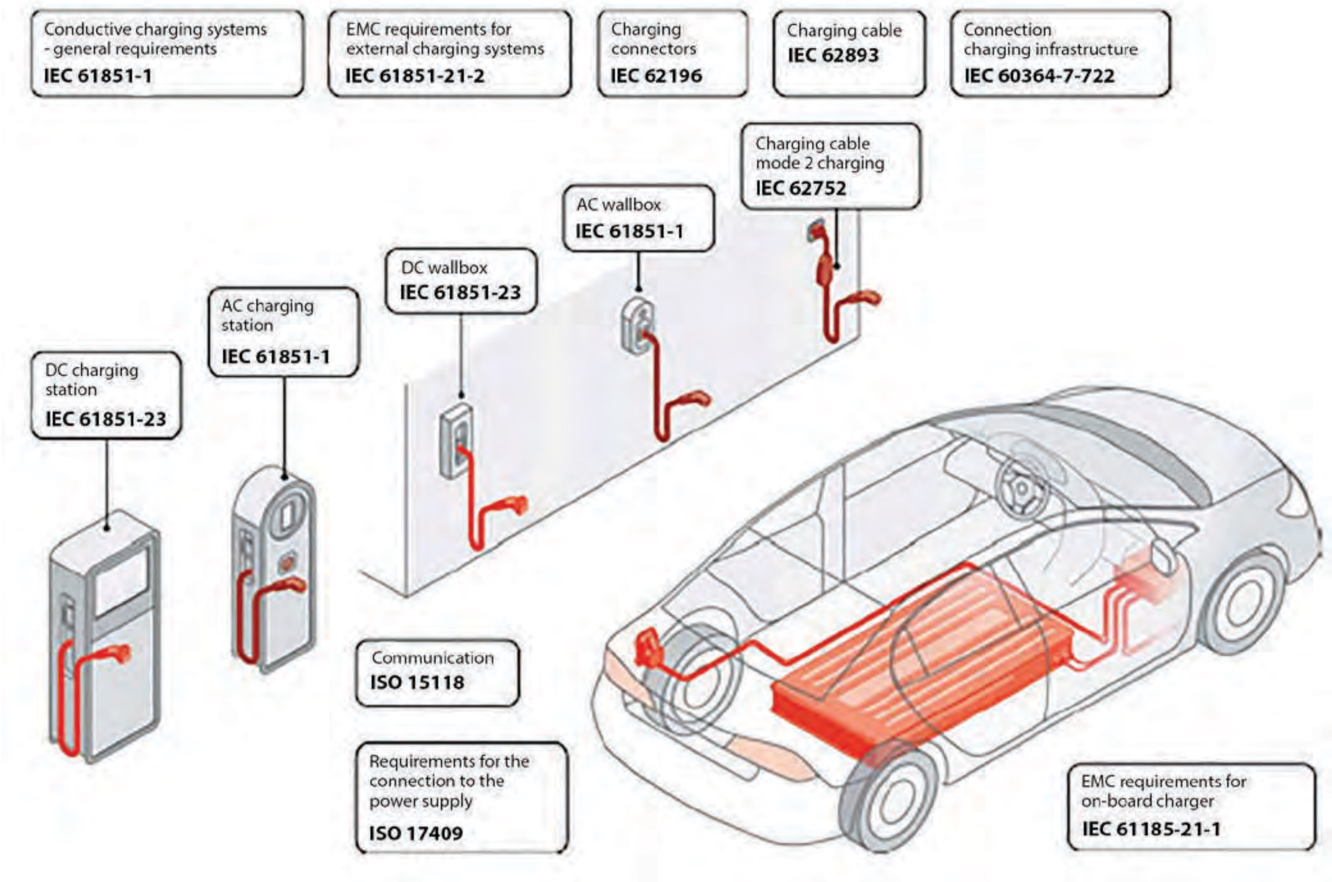


Figure 13: Wired charging and related standards of EVs (Nationale Plattform Elektromobilität)

Standards for electric mobility are developed for different application areas by various organisations, e.g., IEC (International Electrotechnical Commission), ISO (International Organization for Standardisation), and SAE (Society of Automotive Engineers International). An overview of the ISO and IEC standards on conductive charging is shown in Figure 13. Other programs are also collaborating to develop standards for fast charging: The CharIN initiative promotes the CCS (Combined Charging System) standard and the CHAdeMO association coordinates the CHAdeMO standard.

Table 1: List of Standards for EV charging

Standard	Title
ISO 6469	Electrically propelled road vehicles – Safety specifications
ISO 17409:2020	Electrically propelled road vehicles – Conductive power transfer – Safety requirements
ISO 26262	Road vehicles – Functional safety
ISO 15118	Road vehicles – Vehicle to grid communication interface
ISO 19363	Electrically propelled road vehicles – Magnetic field wireless power transfer – Safety and interoperability requirements
IEC 61851	Electric vehicle conductive charging system
IEC 60664	Insulation coordination for equipment within low-voltage systems
IEC 60990	Methods of measurement of touch current and protective conductor current

Standard	Title
IEC 61000	Electromagnetic compatibility (EMC)
IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
IEC 62196	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles
IEC 61980	Electric vehicle wireless power transfer (WPT) systems
IEC 62752	In-cable control and protection device for mode 2 charging of electric road vehicles (IC-CPDs)
IEC 60364	Low-Voltage electrical installations
IEC 62913	Generic smart grid requirements
IEC 62660	Secondary lithium-ion cells for the propulsion of electric road vehicles
IEC 61850	Communication networks and systems for power utility automation (including EEBUS)
IEC 63119	Information exchange for electric vehicle charging roaming service
IEC 62893	Charging cables for electric vehicles of rated voltages up to and including 0,6/1 kV
ECE R100	Uniform provisions concerning the approval of vehicles regarding specific requirements for the electric power train
ECE R10	Electromagnetic compatibility (EMC)
SAE J1772	SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler
SAE J2954	Wireless Power Transfer for Light-Duty Plug-in/Electric Vehicles and Alignment Methodology
SAE J2847	Communication Between Plug-In Vehicles and Off-Board DC Chargers
SAE J2183	60 V and 600 V Single-Core Cables
CHAdeMO	CHAdeMO is a DC charging standard for electric vehicles. It enables seamless communication between the car and the charger. It is developed by the CHAdeMO Association, which is also tasked with certification and ensuring compatibility between car and charger.
CCS	Combined Charging System
GB/T 20234	Connection set for conductive charging of electric vehicles (China)
GB/T 18487	Electric vehicle conductive charging system (China)
GB/T 18384	Electrically propelled road vehicles-Safety specifications (China)
GB/T 27930	Communication protocols between off-board conductive charger and battery management system for electric vehicle(China)
OCPP	Open Charge Point Protocol
EEBUS	language for devices to communicate about energy
OpenADR	The OpenADR Alliance was created to standardize, automate, and simplify Demand Response (DR) and Distributed Energy Resources (DER)

Different standards can be applied for different communication applications like vehicle to charging station or charging station to charging station operator backend.

Several standards can be pertinent in each application area. Table 1 shows a list of common standards. The charging station for conductive charging is covered by IEC 61851, SAE J1772, and GB/T 18487 standards, while the plug, socket and cord are covered separately in the IEC 62196, SAE J1772, GB/T 20234, IEC 62893, SAE J2183, ChaDeMo, and CCS standards. Communication is also addressed in separate standards such as ISO15118, IEC 61851, SAE J2847, GB/T 27930, CCS, and ChaDeMo. Different standards can be applied for various communication applications like vehicle to charging station or charging station to charging station operator backend.

In addition to the standards addressing electric vehicle charging, national requirements for electrical installation must be met, e.g., VDE-AR-N-4100 in Germany. Several standards could be applied to the components onboard EV, e.g., LV123 and LV124 for electric components and high-voltage components in automobiles.

An essential intention of such standards is the protection of humans. In this report, only some requirements for AC and DC charging systems are elaborated as an example. The IEC 61851-1 standard imposes several requirements for AC charging systems. One important requirement is installing a Residual Current Device (RCD) type B a with rated current of 30 mA or an RCD type A with an additional circuit to interrupt the supply for DC fault currents greater than 6 mA. Another requirement is that the voltage at touchable conducting parts must be lower than 60 V no later than one second after the supply is disconnected.

DC charging systems need to be compatible with an RCD type A according to IEC 61851-23. One second after disconnecting the supply, the voltage at touchable conducting parts must be lower than 60V or the charge between any contact must be lower than 50 µC.

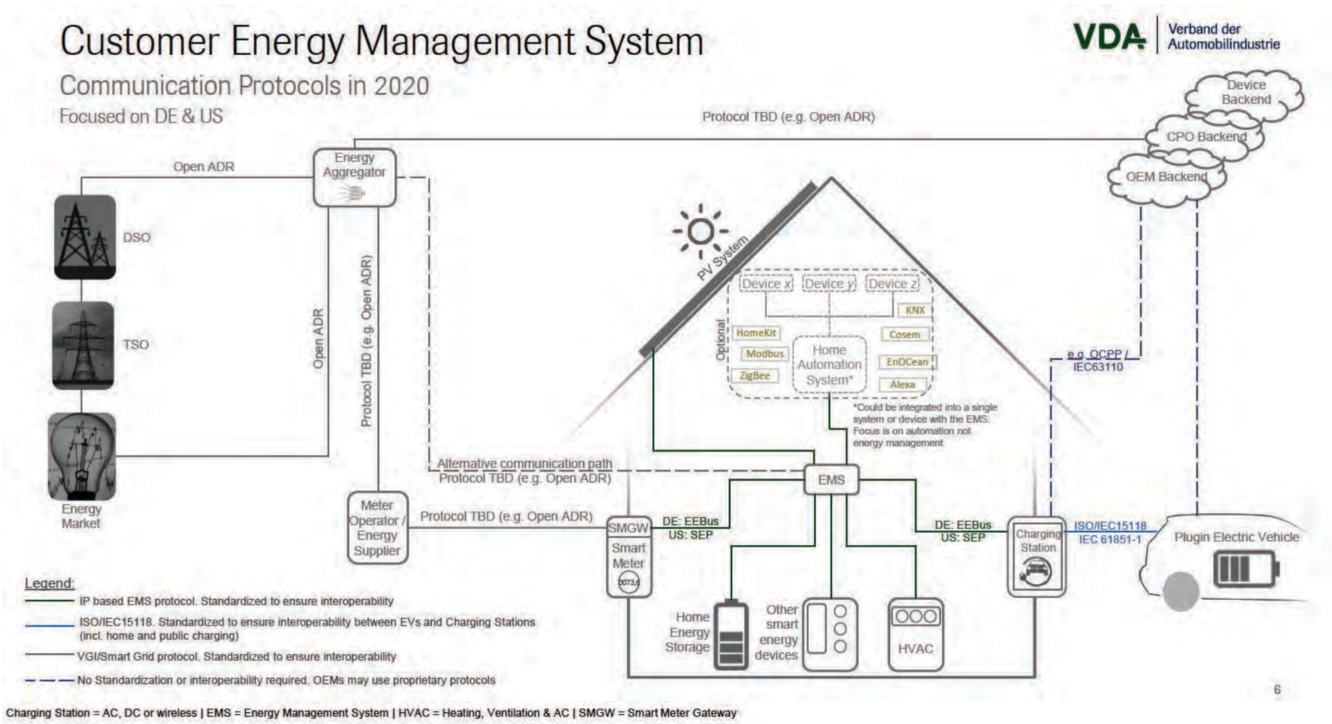


Figure 14: Example for communication infrastructure in private households with possible communication protocols for different applications (Verband der Automobilindustrie 2020)

IEC 61851 allows basic information on the charging process to be exchanged between the vehicle and the charging station on the basis of analog communication.

3.4 Communication protocols

For a smart charging infrastructure, several communication paths must be covered. Figure 14 shows an exemplary overview of these channels for households with a charging station.

3.4.1 COMMUNICATION BETWEEN ELECTRIC VEHICLE AND CHARGING STATION: IEC 61851 AND ISO 15118

IEC 61851 allows basic information on the charging process to be exchanged based on analog communication between the vehicle and the charging station. The charging station uses the so-called duty cycle of a pulse width modulation (PWM) to signal the maximum supported current, among other things. The vehicle can transmit its current status via a resistance identifier, such as "Ready to charge" or "Ventilation required" (for charging processes in closed rooms/garages). The standard is implemented in all relevant charging stations and electric vehicles in Europe and represents the de-facto standard.

The **ISO 15118** standard is based on IEC 61851 and supplements it with digital communication via Powerline. This makes it possible to exchange more complex information such as the vehicle's charging status and battery capacity, tariffs, and charging schedules. The primary function enabled by the standard is so-called "smart charging". For this purpose, charging capacity, charging time, energy costs, and billing modalities are transferred between the charging station and the EV, and the car is charged when energy is cheap. The Open Charge Point Protocol (OCPP) is provided for communication between the charging station and its operator. Furthermore, grid connection and long-term aspects of smart grids/use of BEVs as distributed storage are supported. A charging schedule is applied that takes into account available energy and the expected mobility demand. The charging process can be adjusted spontaneously. The communication is based on Transmission Control Protocol/Internet Protocol (TCP/IP), Dynamic Host Configuration Protocol (DHCP), and Programmable Logic Controller (PLC). The Vehicle-to-Grid Transport Protocol (V2GTP) is used as the communication control layer, while a minimalized XML protocol and so-called V2G messages are used on the presentation/application layer.

The Open Charge Point Protocol (OCPP) is provided for communication between charging station and charge station operator.

The main advantage for the driver is that the identification and billing processes are automatic, based on the plug-in and go ("Plug&Charge"). In principle, the user can choose when to drive off again and the system ensures the optimal charge depending on that information.

The security of the standard is based on Transport Layer Security (TLS) and the matching of digital certificates that originate from a Grid Root Certificate Authority (V2G Root CAs). There can be several of these, which can certify each other. Hubject and Penta Security, for example, are such V2G Root CAs.

The OSCP (Open Smart Charging Protocol) transmits forecasts of capacity availability on the power system from the DSO (distribution system operator) to the Charge Point Operator (CPO).

ISO 15118 is expected to become very important for public charging infrastructure in the coming years. However, a "retrofitting" of existing charging systems supporting IEC 61851 is not to be expected across the board. Therefore, both the standards will still be prevalent in the field for years to come.

3.4.2 COMMUNICATION BETWEEN CHARGING STATION AND IT BACKEND: OCPP, OSCP, IEEE 2030.5, OPENADR, EEBUS

The Open Charge Point Protocol (OCPP) is used to connect charging stations to the operator's IT backend. There are various versions in circulation. Currently, the versions OCPP 1.5 and 1.6 (used by ebee, Mennekes, wallbe, etc.) are most frequently used. OCPP 1.6 defines two alternative transport channels and uses the technologies including Simple Object Access Protocol (SOAP) or JavaScript Object Notation (JSON) -Websockets. The upcoming version OCPP 2.0 is adapted to charging stations with ISO 15118 support but is not yet in use. The IEC 63110 standard is currently being developed as a competitor to OCPP.

The OSCP (Open Smart Charging Protocol) transmits forecasts of available capacity on the power system from the DSO (distribution system operator) to the Charge Point Operator (CPO). It can be used between the DSO and the CPO as well as between the CPO and the HEMS (Home Energy Management System) to transmit a 24-hour capacity forecast. OSCP uses OCPP for communication between the CPO and the local controller.

The IEEE 2030.5 standard ("Smart Energy Profile Protocol") concerns the interface between smart grid and users. This standard enables energy management at the end-user, including demand response, load control, communication of prices, distributed generation, storage and EV, as well as other resources including water, gas, and steam. The standard defines mechanisms for message exchange and security features. It allows several possible architectures and usage models, including communication directly between prosumer and service provider, within a Home Area Network (HAN), and between service provider and aggregator. The standard uses several elements from its other counterparts as sources, including IEC 61986 and 61850, and uses RESTful services.

OpenADR (Automated Demand Response) was developed in 2009 by Lawrence Berkeley National Laboratory (USA) as a standard for automated load management. In 2010, the OpenADR Alliance was formed, which today sees the standard as an open, highly secure smart grid standard. OpenADR was deployed in California's automatic load management programs starting in 2013. The standard is 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.

The IEEE 2030.5 standard ("Smart Energy Profile Protocol") concerns the interface between smart grid and users.

EEBus is a communication interface for energy management on the Internet of Things. It was developed as part of the SmartWatts research project in the E-Energy funding program and is being further developed by the members of the EEBus Initiative e.V. association, which was founded in 2012. Members include various manufacturers of charging infrastructure, including Mennekes, ABB, and ebee. Historically, EEBus focuses strongly on communication between devices of private end customers (e.g., household appliances) and local energy management systems. It is vendor-independent and interoperable with various smart home standards, e.g., KNX or ZigBee. Further development takes place in so-called working groups, which develop standardized use cases. One of the working groups has the title "E-Mobility & Connected Car". Since 2015, the VDA (German Association of the Automotive Industry) has also been a member of the EEBus initiative.

The standard is available in version 2.0 and allows the exchange of price signals, setpoints, and metered values between loads, electric storage, distributed generators, and electric vehicles on the one hand, and energy providers and aggregators on the other.

3.4.3 COMMUNICATION BETWEEN CHARGING STATION AND E-MOBILITY SERVICE PROVIDER (EMSP): OICP, OCPI, OCHP, EMIP

This type of interface is determined by de facto standards and technologies adopted by the eMSP.

The OICP (Open Intercharge Protocol) is published by Hubject and is used to exchange information between the Hubject eRoaming platform and Charge Point Operators (CPOs) or electric Mobility Service Providers (eMSP). The Hubject platform is positioned between the CPO and the eMSP. The standard enables authorization and dynamic pricing of charging processes. Communication is based on SOAP and Representational state transfer (REST).

OCPI (Open Charge Point Interface) is used to connect electric Mobility Service Providers (eMSP) and CPOs. It can be used in P2P as well as with hubs such as GIREVE and e-clearing.net. It enables authorization, CP status transmission, remote CP control, the transmission of charging details, and prices and tariffs.

OCHP stands for Open Clearing House Protocol. It is used to connect local (country-specific) charging networks via a clearing house. The clearing house (e.g., e-clearing.net) acts as a “neutral” intermediary, e.g., between CPOs and eMSPs.

The eMIP (eMobility Inter-operation Protocol) is used for data transmission between GIREVE, a French e-roaming platform, and CPOs, eMSPs as well as Data Aggregators. It is used to (i) support roaming of charging services through authorization and a clearing house API and (ii) allow access to a charging station database. eMIP allows CPOs, Data Aggregators (holding information about charging stations including locations) and eMSPs to access the so-called GIREVE platform. A CPO can, for example, verify the authorization of an end customer via the platform.

3.5 Power Electronics

As shown in the block diagrams in Figure 4 - Figure 6, two converters are in the charger. The first one realizes the grid connection, and the other one supplies the battery. This two-stage concept is typically used in on-board chargers.

In this section, various topologies are given for the two separated stages, and several implementation possibilities for the power electronics of complete chargers are presented.

3.5.1 GRID CONNECTION AC/DC CONVERTER

In principle, three categories of converters can be considered to realise a three-phase grid connection: unidirectional converters (with and without the ability to provide reactive power) and bidirectional converters. For all the categories, single and three phase topologies are feasible.

Unidirectional converter topologies

As shown in Figure 15, a diode rectifier is a simple and inexpensive option, which only realizes unidirectional power flow to the battery.

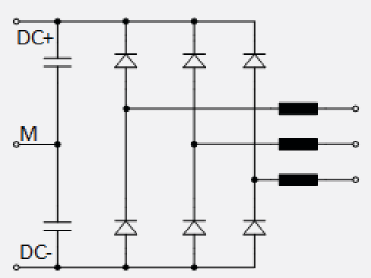


Figure 15: Diode Rectifier

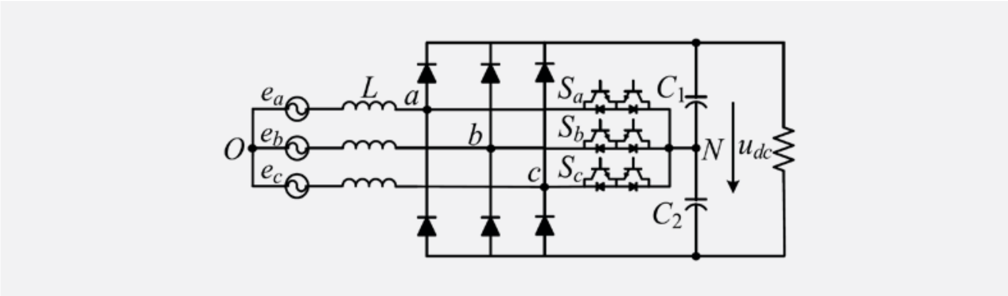


Figure 16: **Vienna Rectifier (Feng et al. 2019)**

To provide reactive power, it is necessary to add power factor correction (PFC) to the diode rectifier or to use an active rectifier topology such as the **Vienna rectifier** shown in Figure 16. The Vienna rectifier is a three level rectifier which allows the reduction of the inductor size by increasing the switching frequency (Kolar und Drofenik 2000).

Bidirectional converters

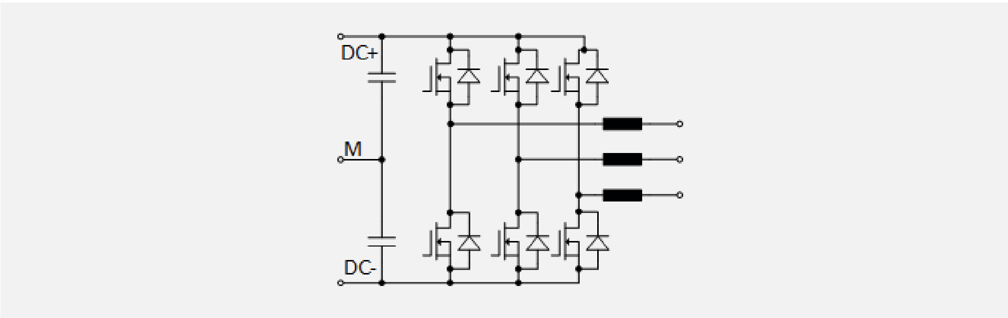


Figure 17: **Active front end -B6**

To deliver the complete list of grid friendly functions (refer to Table 2), an **active front end** such as the B6 topology is required, enabling bidirectional power flow and displayed in Figure 17. Only six switches are required, which represents the easiest way to realize a bidirectional AC/DC converter.

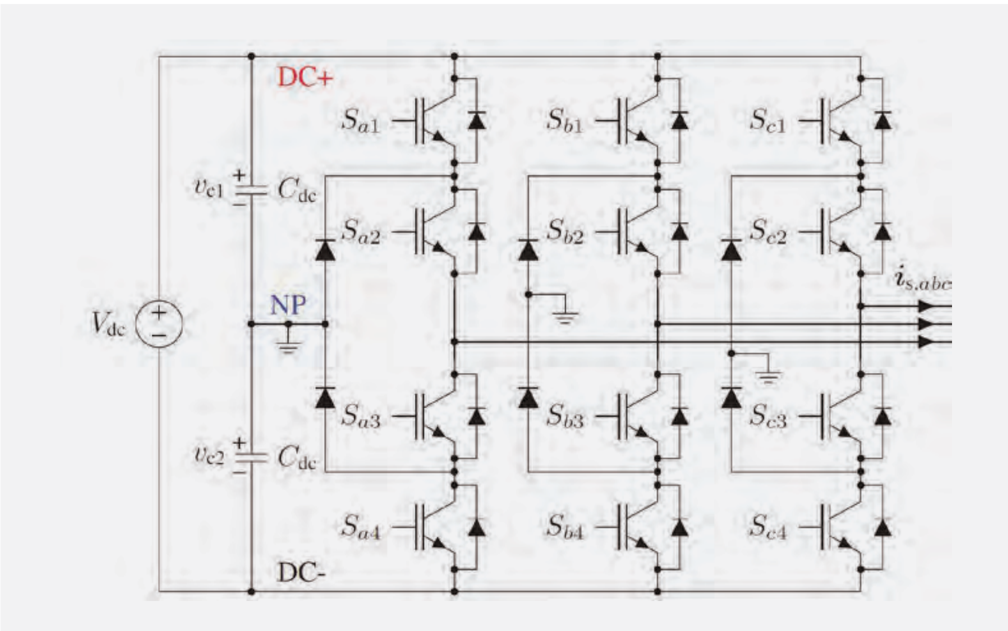


Figure 18: **Three-phase neutral point clamped converter (Stolze et al. 2015)**

Adapting coordinated control strategies for a three-level topology can help reduce the inductor size by reducing current ripples. Figure 18 shows the neutral point clamped converter. The additional advantage of this specific circuit is that the switches only need to withstand half of the DC voltage, which results in lower switching losses. On the other hand, the conduction losses increase. The topology uses controllable switches and diodes, so that an asymmetrical loss distribution occurs. For reducing the asymmetrical losses, the diodes in the topology are replaced with controlled switches, resulting in the Active Neutral Point Clamped Converter Topology (ANPC) (Habib et al. 2020). A drawback of the ANPC is the high number of active switches. A possible trade-off is the T-Type Neutral Point Clamped Topologies (TNPC). A single leg of the TNPC is displayed in Figure 19.

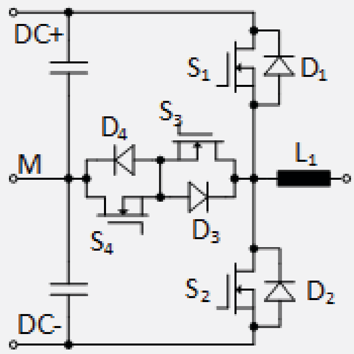


Figure 19: T-Type Neutral Point Clamped Topologie (TNPC)

For the TNPC, four switches are necessary. The switches S1 and S2 need to block the full DC voltage while the other switches need to block only half of the DC voltage.

The preferable choice of the bidirectional topology depends on many factors: cost, weight and volume, desired switching frequency and efficiency, the complexity of the control circuitry, and more. Therefore, all the topologies might be applicable depending on the use case.

Single phase converters

For a unidirectional single-phase grid connection, a diode rectifier (with optional PFC) is suitable. To realize bidirectional power flow, the H-Bridge (Figure 21) is the first choice, and the half bridge (Figure 20) is probably an alternative which is currently under investigation at Fraunhofer IEE.

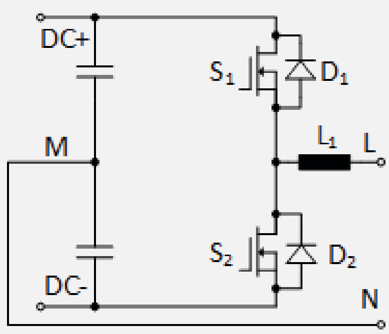


Figure 20: Half bridge with midpoint connection

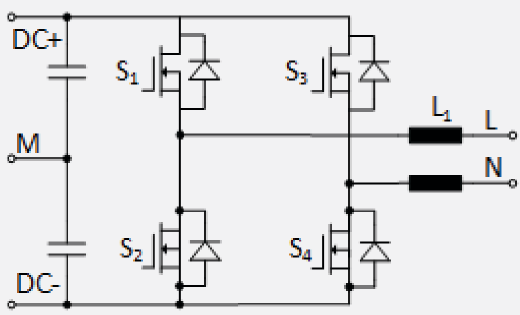


Figure 21: H-Bridge

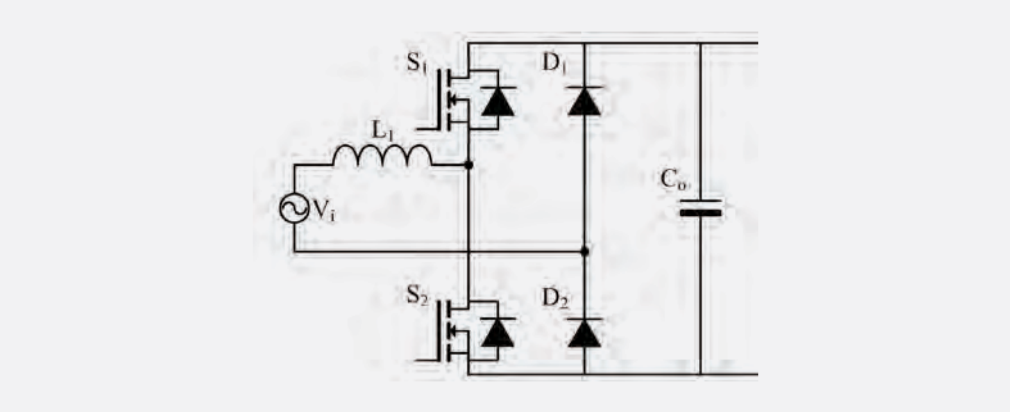


Figure 22: **Totem Pole PFC (Firmansyah et al. 2010)**

The half bridge requires only two active switches, but the DC voltage required to feed into the grid is twice as high compared to the H-bridge. Depending on the control strategy, the H-Bridge with four switches can provide two or three-level current, helping reduce the inductor size.

The Totem Pole PFC is a modified H-bridge to provide unidirectional power flow and reactive power and is shown in Figure 22. The advantages are reducing of the count of active switches and the possibility to use zero-volatge soft-switching, which improves the efficiency (Firmansyah et al. 2010).

3.5.2 BATTERY CONNECTION – DC/DC CONVERTER

For implementing the battery connection, several types of DC/DC converters can be used. In this section, resonant converters, full bridge isolated converters and conventional converters in unidirectional and bidirectional configuration are discussed briefly.

For DC chargers, galvanic isolation is usually required for safety reasons. For AC chargers, the use of galvanically connected converters is possible, resulting in lower cost, weight, and volume as well as higher efficiency. Today galvanically isolated AC chargers are the standard solution. But related to its benefits, a trend towards galvanically connected converters is foreseen. This trend can be anticipated by observing the development of photovoltaic converters for residential applications.

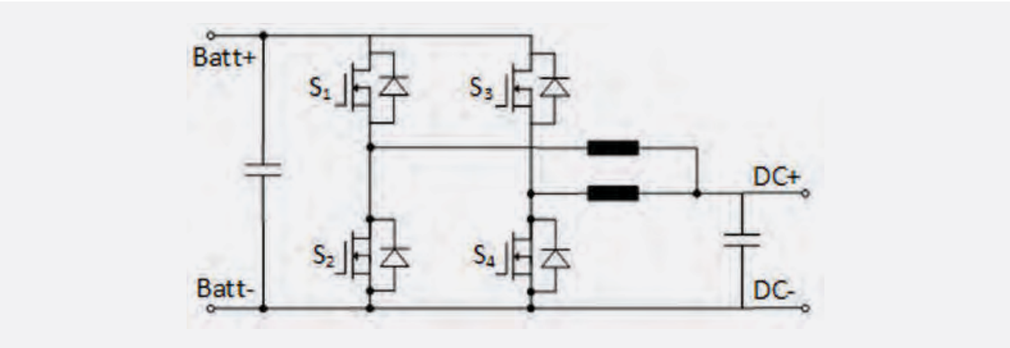


Figure 23: **bidirectional 2-phase DC/DC converter**

Depending on the voltage level, a conventional buck or boost converter is the easiest way to implement the galvanically connected DC/DC converter. Figure 23 shows an upgraded variant of those. The diodes are replaced by active switches to provide bidirectional power flow. A second phase is added to reduce the necessary current rating of the semiconductors and inductors, thereby reducing the inductor size, volume, and weight.

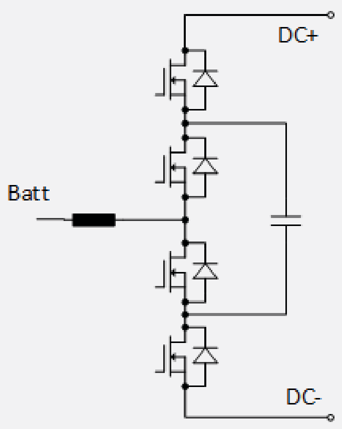


Figure 24: **Flying Capacitor DC/DC converter**

A similar reduction in inductor size and semiconductor rating can be achieved by using a so-called flying capacitor. The result is a three or more level topology. A possible option for realizing a flying capacitor DC/DC converter is shown in Figure 24. The displayed type is bidirectional, but a unidirectional implementation is possible as well.

Isolated Converters

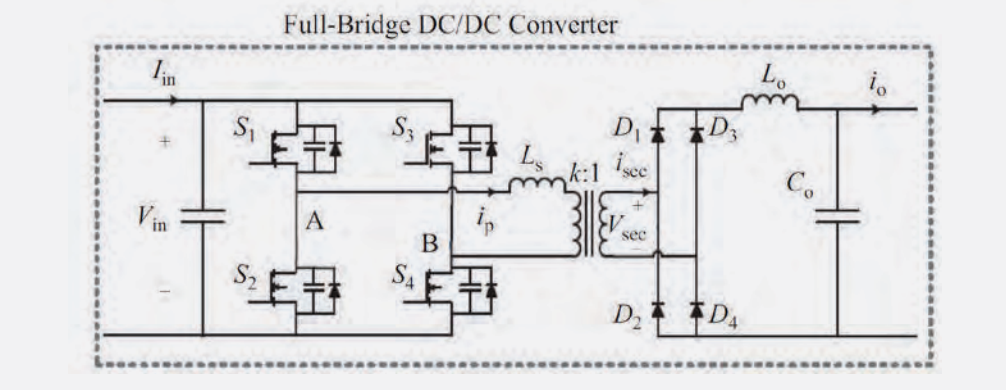


Figure 25: **Full-Bridge DC/DC Converter (Habib et al. 2020)**

Figure 25 shows a DC/DC converter with isolation. The transformer galvanically isolates the battery side from the rest of the charging system. A full-bridge is used to create a kind of AC signal from the rectified current. Behind the transformer, the AC power is rectified again. Usually, a high frequency is used to reduce the size of the transformer. The rectifier on the secondary side is replaced by another active full-bridge for bidirectional application, resulting in the Dual Active Bridge (DAB) topology, as displayed in Figure 26. The bridge on the secondary side can also be replaced by a variant of the flying capacitor converter.

For reducing conduction losses, resonant converters are the suitable choice, whereas soft-switching (Zero Voltage Switching – ZVS, Zero Current Switching – ZCS) reduces switching loss.

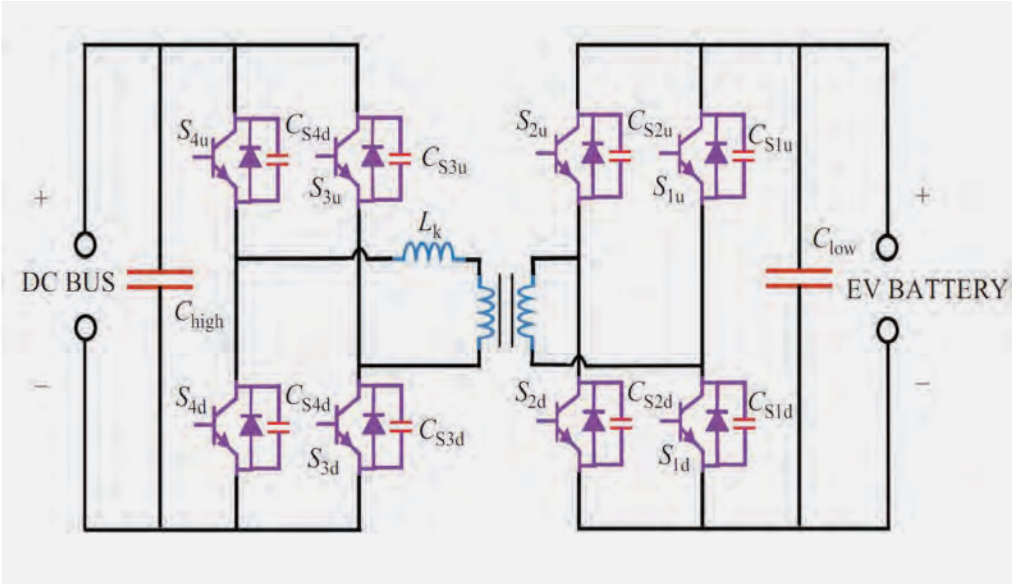


Figure 26: **Dual Active Bridge (DAB) (Habib et al. 2020)**

Resonant Converters with Galvanic Isolation

Resonant converters are the suitable choice for reducing conduction losses, whereas soft-switching (Zero Voltage Switching – ZVS, Zero Current Switching – ZCS) reduces switching loss. So, the combination of resonant and soft-switching effectively reduces the overall losses. Different soft-switching resonant converters used for EV charging are given in Figure 27.

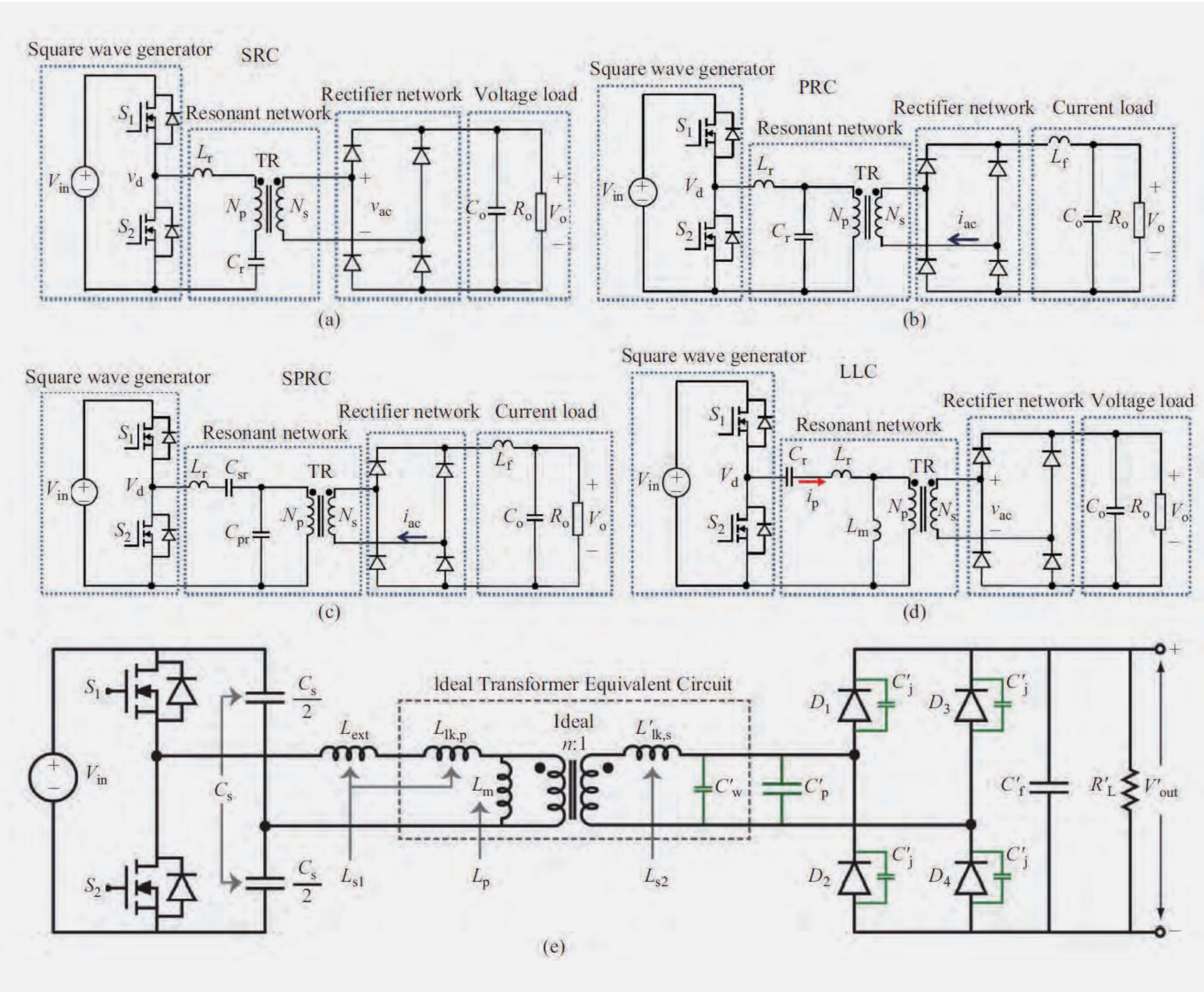


Figure 27: Types of resonant converters a) Series resonant converter b) Parallel Resonant converter c) Series parallel resonant converter d) LLC converter e) L3C2 converter (Habib et al. 2020)

The Series Resonant Converter (SRC) has a series combination of an auxiliary inductor, capacitor, and network load. During the operation of SRC, the combination of L, C, and load acts as a voltage divider circuit. Modulation of the frequency of driving voltage changes the impedance of the resonant circuit. ZVS and ZCS both are applicable in SRC to reduce losses, thereby increasing efficiency (Habib et al. 2020). The Parallel Resonant Converter (PRC), a parallel combination of load and a resonant circuit is implemented in PRC, whereas the series inductor is placed with the load for impedance matching. The series-parallel resonant converter (SPRC) is a combination of series and parallel resonant converter and consists of an auxiliary inductor and two capacitors in series and parallel with an isolation transformer. This combined topology improves the characteristics of the converter in terms of control energy, output voltage regulation and sensitivity. SPRC has low circulating energy as compared to the PRC and is less sensitive to load variations. Other than this, traditional converters, LLC converters are popular in the EV charging domain. It can be implemented with a full-bridge or the requirement of EV charger design (Habib et al. 2020).

The constructional design of the resonant circuit is slightly different from the usual design. The inductor is placed in parallel with the magnetizing inductor, and a series combination of L and C is in series with the magnetizing inductor. In such a design, the series combination of L and C is responsible for higher frequencies, whereas series and parallel inductors are responsible for lower frequencies. It allows zero voltage and current switching that creates an appealing change in the operating region and characteristics of the charger compared to conventional converters. A new multi-resonant converter named L3C2 is introduced in the recent literature on EV charging applications. Increased inductor and capacitor combination allows operation over wider ranges and reduces noise in the output voltage.

3.5.3 SILICON VS. SILICON CARBIDE

For improving the efficiency of normal and fast chargers built from subunits, it is possible to replace silicon (Si) diodes and active switches with silicon carbide (SiC) devices. As an example, the Vienna rectifier is considered. Using SiC diodes instead of Si improves efficiency by about 0.8%. Replacing Si IGBTs with SiC MOSFETS increases efficiency by another 0.5% (Infineon Technologies AG 1.19). However, the cost of SiC devices is higher, but the cost difference has narrowed in recent years (Higgelke 18.10.20).

Using SiC diodes instead of Si improves efficiency by about 0.8%. Replacing Si IGBTs with SiC MOSFETS increases efficiency by another 0.5% (Infineon Technologies AG 1.19)

3.5.4 IMPLEMENTATION POSSIBILITIES

In this subsection, a selection of charger topologies will be displayed and discussed briefly.

Two Stage Charger

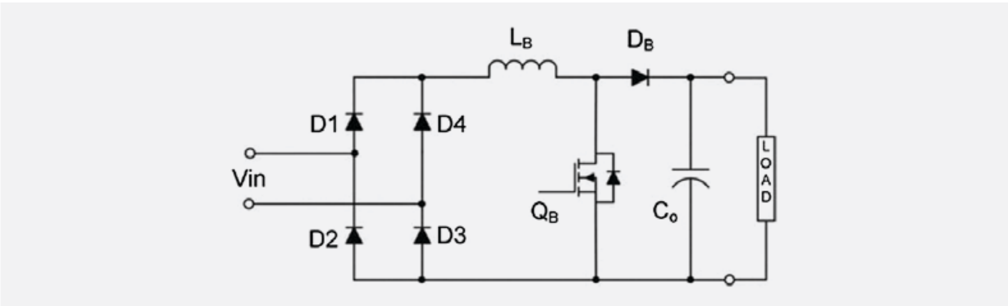


Figure 28: **Full-bridge rectifier with a boost converter (Nguyen und Lee 2018)**

Figure 28 shows a basic single phase charging system without galvanic isolation. As galvanic isolation is mandatory for offboard chargers, this topology is only suitable for onboard chargers. By substituting the diodes with active switches, a bidirectional topology is realized. For an offboard charging system, the boost converter could be changed to a galvanically isolated type (refer to Figure 29). For higher charging power, the grid connection is usually realized with three phases using, for example, the B6 topology, which is also displayed in Figure 29.

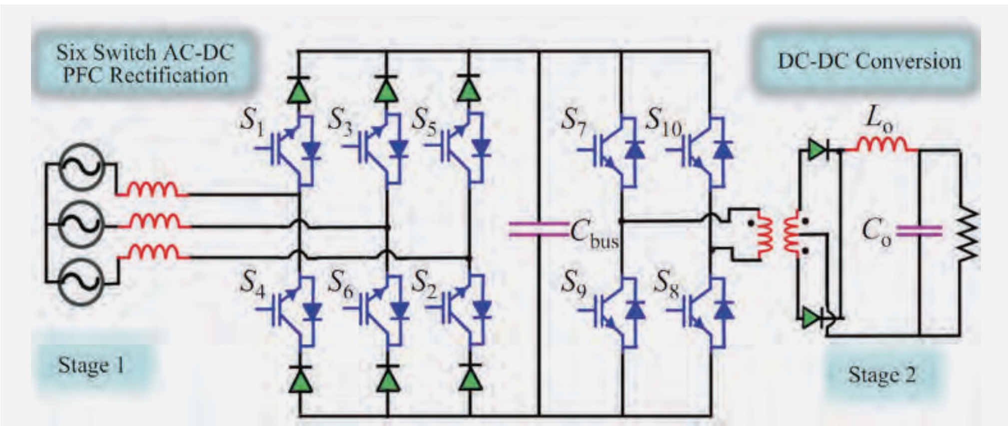


Figure 29: **Two stage three-phase charger with galvanic isolation (Habib et al. 2020)**

Single Stage Charger

Single-stage chargers are possible to realize if low cost is the target. This charger type suffers from a limited conversion ratio, limiting their application in EV charging (Brenna et al.) and is therefore not discussed here.

Integrated Onboard Chargers

The concept of integration is based on reusing the drivetrain components, especially motor windings, and the inverter. This concept allows very high AC charging power with a low number of additional components. First commercial systems are available (Continental) but have not yet gone into large-scale production. A lot of topologies were proposed but they suffer from different drawbacks. Some require access to inaccessible areas of the motor windings or rearrangement of the windings. Another drawback is the higher complexity of the topology and increased stress on the components (Brenna et al.).

Multifunctional Onboard Chargers

The term 'multifunctional' is used in different charger concepts, two of which are described in this section: A charger with included low-voltage battery charger and a charger that combines different charging possibilities with as few components as possible.

Figure 30 shows an advanced multifunctional onboard charging system, which combines bidirectional AC charging for single and three phase charging with the possibility to use inductive charging. The concept, which was developed at Fraunhofer IEE, is proposed in (Jung 2016). The idea is to maximize flexibility in the choice of charging solution while adding as little weight and cost as possible.

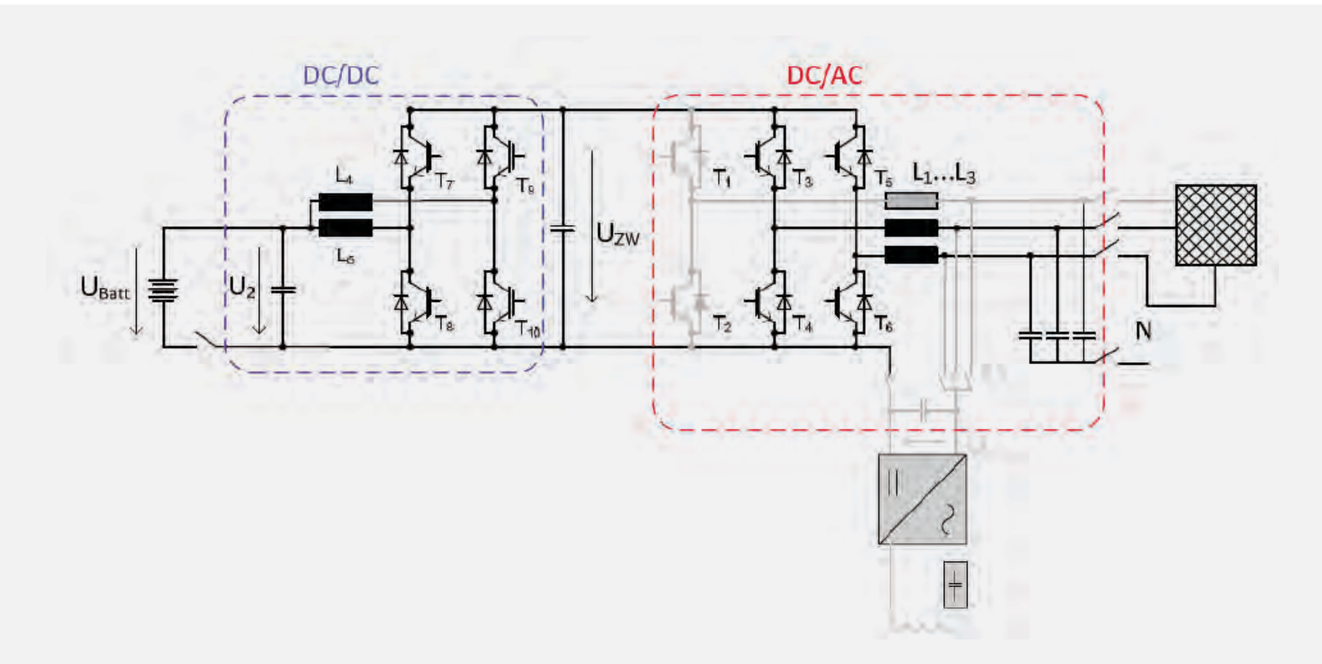


Figure 30: **Multifunctional bidirectional charging system (Jung 2016)**

Another possibility is to include the charger of the low voltage battery into the charging system of the traction battery and to share components to reduce weight, volume, and cost. A possible single-phase configuration is shown in Figure 31.

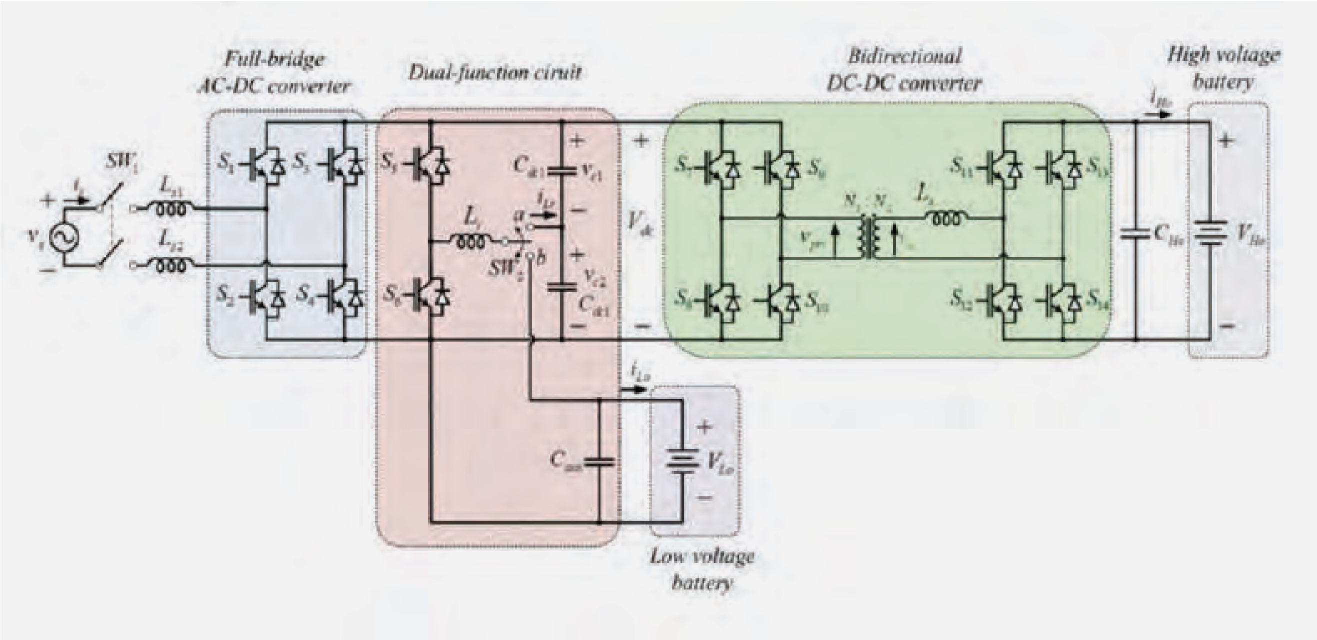


Figure 31: Multifunctional OBC proposed in (Nguyen und Lee 2018)

3.6 Smart Control functionalities

The generally high parking time of vehicles of 23 hours on average (Arnold et al. 2015) makes it possible to consider the vehicle battery for other applications. In principle, it is also possible to feed electricity back into the grid for grid stability reasons or monetary gain.

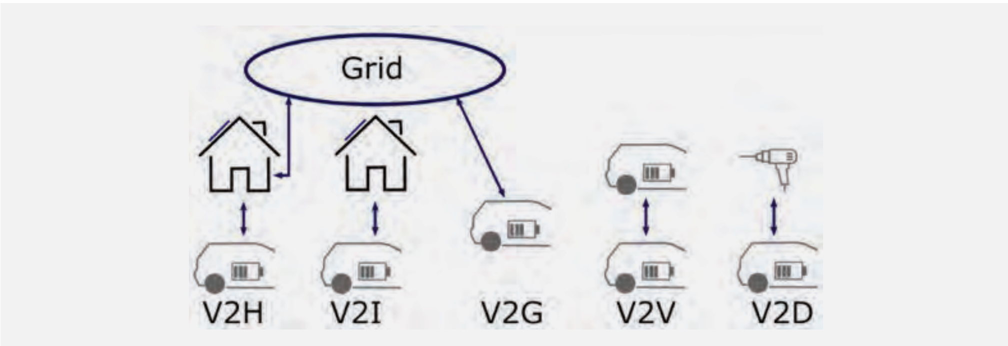


Figure 32: Different applications of the BEV traction battery

The EV battery can be used in several ways, as shown in Figure 32 and explained below.

- Vehicle-to-home (V2H) systems enable intermediate storage of locally generated electricity (e.g., by photovoltaics) and temporary supply the building from the vehicle battery. Likewise, there is the possibility of exploiting time-variable purchase prices.
- Vehicle-to-Island (V2I) is the supply of electricity to a building from the vehicle battery when the grid connection is interrupted or unavailable, creating a microgrid. This enables the supply of electricity during technical snags in the power grid or disaster situations.
- Vehicle-to-grid (V2G) enables the provision of system services for the power grid. This includes controlled charging, energy recovery (BDWE 2017), reactive power for voltage control and active power for frequency control.

V2V, V2D and V2I functions have no direct relevance for the electric grid.

- Controlled charging (V1G) enables the postponement of charging operations during periods of high grid utilization, the so-called “grid- and system-serving flexibility”. Control can take place via market incentives or intervention by the grid operator. For charging systems with rated power greater than 12 kVA, a control system in accordance with the German VDE-AR-N 4100 standard must be provided. With the assistance of local charging management, it is possible to increase the number of charging points for the same grid connection power and thus to operate more electric vehicles for the same grid connection fee.
- Vehicle-to-vehicle (V2V) systems allow a traction battery to be charged from the battery of another vehicle with the appropriate equipment.
- Vehicle-to-Device (V2D) makes it possible to supply electrical appliances intended to connect household or industrial sockets from the vehicle battery. Examples of application areas include supplying power tools, providing emergency power during disasters, or operating consumer electronics such as an electric grill in off-grid areas.

V2V, V2D and V2I functions have no direct relevance for the electric grid. Possible grid-friendly function within V1G and V2G concepts are collected in Table 2 to show the potential benefits for grid stability and cost reduction. The grid may also benefit from V2H functions. The benefit varies with the configuration of the V2H system, whether it is focused on maximizing the consumption of locally generated energy or on peak shaving.

3.6.1 GRID FRIENDLY FUNCTIONS

Table 2: Grid friendly functions

Grid friendly function	Benefit	Normative mandatory Exemplary in Germany
Voltage stability		
Low-Voltage-Ride-Through (LVRT)	Withstand the system for voltage dip condition for a limited time	Bidirectional systems with MV access
Q(U)-characteristic	Local voltage stability	Yes
Power factor correction	Controlled voltage stability	Yes
Frequency stability		
Active power limitation	Power balance	Yes
P(f)- characteristic	Local frequency stability	Yes
Active power feedback (V2G)	Provision of operating reserve	No
Grid quality		
Unbalanced load / compensation	Grid quality support	No
Harmonics compensation	Increase in grid quality	No
Grid restart (after blackout)	Security of supply	No
Island detection	Safety shutdown in case of a blackout	Yes

3.7 Comparison Framework of Commercially Available EV Chargers

Comparison between EV chargers is based on various technical and economic parameters. The functionality of chargers, namely, fast and slow chargers and the applicable vehicle segments are also the major factors in EV charger comparison. Factors governing comparison between commercially available chargers are given below:

Output rating

Based on the maximum output power rating of the charger, charging can be differentiated into slow and fast charging. Chargers with lower output ratings have comparatively slower charging speed, and hence, charges with a high rating are implemented for fast charging.

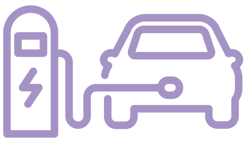
Connector type

The connector type differentiates the chargers as a dumb or smart charger. Different connectors have different maximum ratings, which affects the speed and applicability of chargers. Smart connectors are primarily preferred in public charging stations to allow the active control of charging. Connectors also have different allowed modes and levels of charging, which also establishes charger comparison. Non-standardised connector designs restrict the scope of chargers. Adaptors that increase chargers' interoperability with different vehicle inlet types are introduced in markets to mitigate this issue.

Efficiency

It is a deciding factor while adopting the charger and performing cost analysis for cost recovery and revenue generation.

Cost



Cost is the influencing and deciding factor in the comparison of EV chargers. Cost analysis and other technical specifications and applicability are essential for determining the best choice among commercially available chargers.

Technical specification of an EV charger covers charger type, input and output rating of charger, connector type, number of connector guns, power factor, charger efficiency, level/mode of charging, and communication facilities.

Applicability and Functionality

Based on applicability and functionality, EV chargers are compared. Chargers for a heavy-duty vehicle, quick chargers, and slow chargers are the various available EV chargers.

Vehicle categories

There are various categories of vehicles, namely, 2W, 3W, 4W, light commercial vehicles, and heavy-duty vehicles. Chargers can be compared based on the vehicle segment in which they are most applicable.

EV chargers are broadly classified into two categories: dumb charger and smart charger. Technical specification of an EV charger covers charger type, input and output rating of charger, connector type, number of connector guns, power factor, charger efficiency, level/mode of charging, and communication facilities. A discussion on the technical parameters of chargers is given in Annexure I.

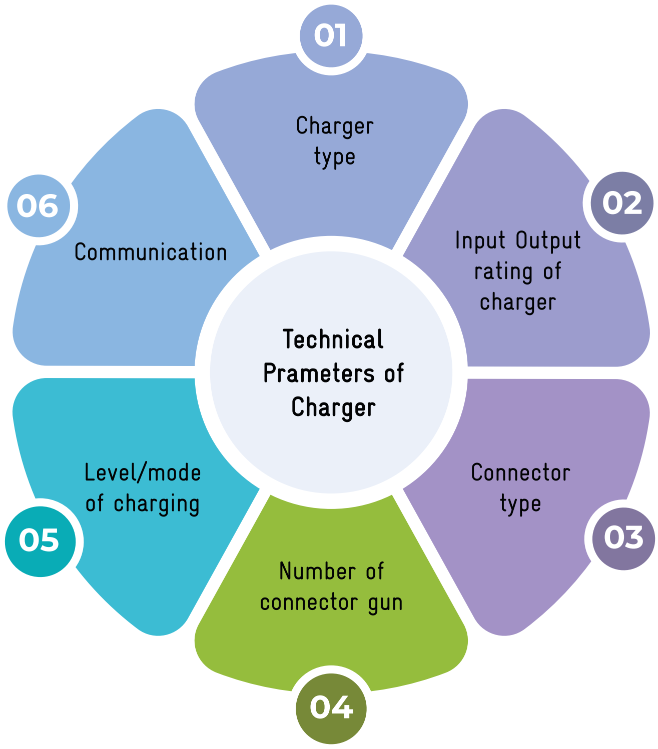


Figure 33: Technical parameters of chargers

3.8 Commercially available Smart Charging products and technologies

Considering tremendous potential benefits of smart charging, several EV smart charging products are already available in the market. These products can be categorized based on their applicability. The scope of applicability of products is network tools, optimisation solutions, charging stations or charging boxes. Network tools can again be classified into interactive communication tools or mobile applications for communication platforms.

Detail information on smart charging products based on applicability are mentioned below.

3.8.1 NETWORK TOOL

A network tool is defined as the tool used to connect to the communication network for indicating the charging request and other information on charging specifications, vehicle specification and authentication. Mobile applications and cloud-based platforms are ways of connecting and communicating with responsible charging entities.

3.8.1.1 PLATFORM

The platform interconnects various EV environment entities to perform computational or storage tasks easily and rapidly. Different platform products available for smart charging are given below:

Snapcharge

It is a computational platform provided by evMega, a Hong Kong-based company ("Products | evmega," n.d.). The platform has the functionality of computational work related to pricing. It allows setting unique and required pricing signals to charging stations, groups of charging stations and charging stations separated by regional boundaries. This platform helps decentralised, distributed, and hierarchical charging strategies due to the ability to set the prices for different locations dynamically.

SnapCharge dashboard in Figure 34 provides real-time charging station's status and EV charging status. Table 3 provides a real-time charging station status covering the number, types, specifications, currently available, and currently working charging points in the station. It also indicates charging prices for a charging status based on the charging type (slow, fast, AC, DC). EV charging status covers the type of charging point to which EV is currently connected, plug-in time, departure time, and expected time duration to complete charging.

Table 3: Information availability on SnapCharge dashboard

	SnapCharge Dashboard	
Types of information status	Real-time charging station's status	EV charging status
Information available	Number of charging points	Type of connected charging point
	Types and specification of charging points	Plug-in time
	Currently available and operational charging points	Time of departure and expected time duration to complete charging
	Charging prices	Charging cost and bill/payment related details

Figure 34: Web view of SnapCharge platform ("Products | evmega," n.d.)

It also performs analyses on charger utilization, income, and charger fault. Charger utilisation analysis covers the utilisation of chargers based on the aggregated time the vehicle is connected and the time for which the vehicle is in charge. Income analysis covers the billing and transaction information for a predefined period. Charger fault analysis covers the fault detection and type of fault that occurred on the charger.

It collects and manages day-to-day data of charging stations, charging orders, and the user's usage data. It also collects users\abnormal cancellation data. The Platform provides the benefit of setting a unique pricing policy to charging stations, groups of charging stations and zones.

Juicenet Platform

JuiceNet platform in Figure 35 is provided by EnelX ("JuiceNet: vehicle-to-grid cloud-based platform for grid balancing.," n.d.). It is a cloud-based EV load management and optimisation platform. Intelligent JuiceNet platform has patented communication and control. It actively manages the charging station's demand using real-time input, charging pattern data, signals from grid operators, utilities, and aggregators. It uses an open API so that it can connect and control any Wi-Fi connected charging station. It coordinates the charging rate and timing of EV. It also provides flexibility to the EV user to override these automatically coordinated parameters during any emergency. JuiceNet offers the following functionalities:

Improving grid reliability

It controls the charging ramp rate and transformer loading, which improves the system's reliability.

Cost-effective solution

It achieves maximum utilisation of system components and efficient utilisation of available power. It reduces the charging cost on each charging session and ultimately reduces the cost burden on customers by reducing the monthly electricity bill.

Reduce emissions and improve local air index

It ensures the maximum utilisation of available energy from conventional and RE generators that reduces the emission from conventional plants. Air quality at a location is also improved because of less conventional generation, more renewable utilisation and more EV adoption.

Reduce EVSE cost

EVSE is an EV supply equipment that supplies charging power to EV via charging point or charging station. JuiceNet platform promotes charging through grid participation incentives.

JuiceNet optimizes EV load and allows increased and efficient EV integration that supports cleaner and efficient transportation than gasoline-powered vehicles. JuiceNet platform is not limited to JuiceNet family products and charging stations, but it also provides its services to global EVSE manufacturers, utilities, and EV customers. It offers visible benefits for EV owners regarding reduced charging cost and indirect benefits for a cleaner environment. It also benefited the system operator and aggregator by maximizing the utilisation of existing equipment and infrastructure.

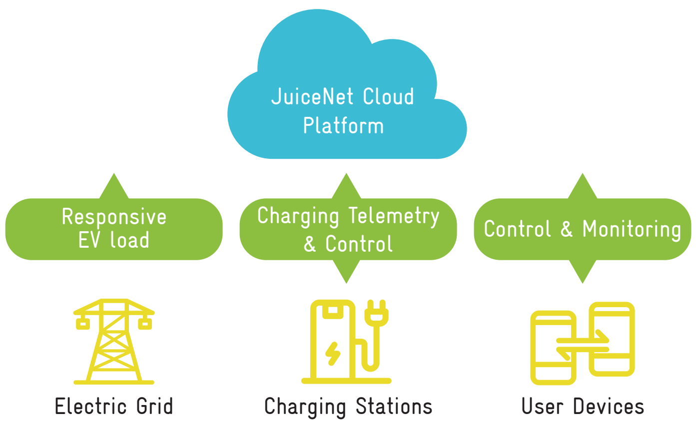


Figure 35: Properties of JuiceNet platform ("JuiceNet: vehicle-to-grid cloud-based platform for grid balancing.," n.d.).

Attractive features of the JuiceNet platform are mentioned below:

Smart dispatch and API access

It provides charging control decisions in the form of charging rates. It dynamically changes as per the local grid conditions and grid constraints. This provides the capability of centralised control using the juiceNet platform. An electricity market-based algorithm considers customers' requirements, choice, and schedule of EVSE as per the grid's available power and other constraining parameters. The platform works on API and IT support utilities, system operators, aggregators, and EV users' interfaces.

Model and data prediction

Predictive event modelling based on historical data of customer's charging behaviour, grid capacity forecast, and electricity market capacity and behaviour is performed for smart charging. Virtual connection and networking of EVSEs perform load sharing. Remote data from EVSE in time-series format is collected and stored for prediction.

EV drivers experience

EV drivers maintain charging station control based on their communicated charging preferences, real-time charging rate, and time of used schedule. It also provides the option to the customer to override the control decision at any time. This interactive platform uses the customer's charging history to provide notifications and alerts and allows users to earn cash rewards in selected regions via JuicePointProgram.

Cloud Energy Car Networking

Cloud energy car networking shown in Figure 36 is an important component in the EV network (Cloud, 1998). It's a cloud-based networking platform and forms an energy internet constitute of EVs. The centralised grid centre and cloud centre has combined computational functionality of taking an optimal charging decision. Optimal charging signals to connected EVs or charging stations act as a charging guide and are visible over the service prompt. EV customers can realise the real-time energy transaction of smart charging stations. It also performs real-time charge settlement by connecting the grid centre and cloud network.

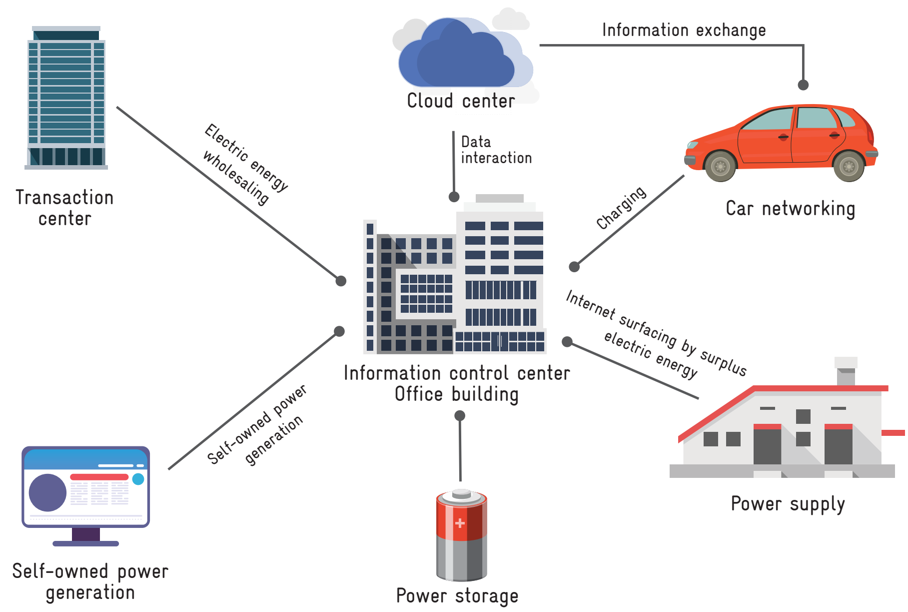


Figure 36: **Network components connected to Cloud energy car networking (Cloud, 1998)**

Physical infrastructure for information flow constitutes transaction centre, conventional and renewable generation, storage units, information control centre and charging infrastructure. In this environment, all the information is first gathered at the information control centre and then passed to the cloud centre connected to the car network. The car network executes scheduling computation and communicates the signal of the charging decision to the respective charging station or EV.

Charge point network and charge point driver experience network

The charge point network is an open, secure and robust charging network focusing on e-mobility and roaming ("ChargePoint Open Network | ChargePoint," n.d.). It partners with charge point operators (CPO) and E-Mobility service providers (eMSP), to perform smart charging and efficient roaming, as shown in Figure 37. The network allows to configure and manage any charging station with a central platform to perform smart charging based on grid and customer requirements.

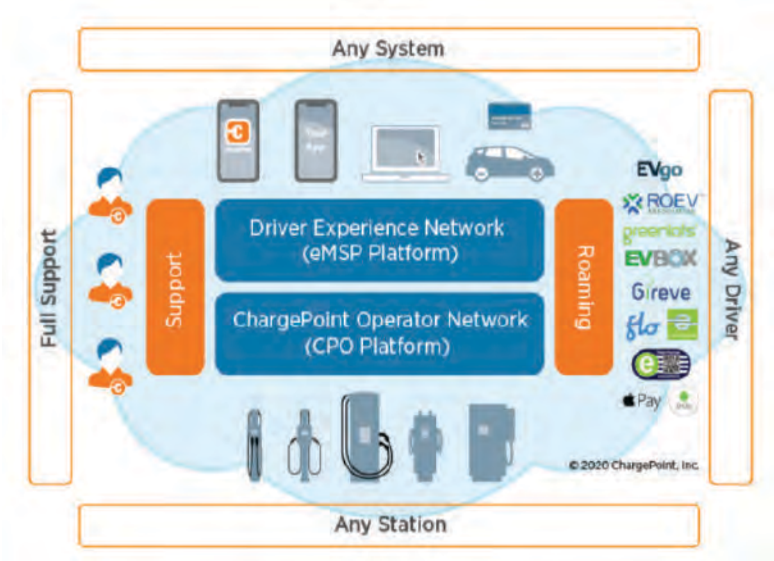


Figure 37: Participants and properties of ChargePoint network ("ChargePoint Open Network | ChargePoint," n.d.)

ChargePoint driver experience network is dedicated for EV drivers to get a better driving experience with simple networking and interface ("ChargePoint's Driver Experience Network," n.d.). It is a cloud-based service designed to combine smart charging with mobile applications and in-vehicle display. It allows smart charging and seamless roaming in Europe and North America. Reservation and charging scheduling provide a smart charging option through this network product.

3.8.1.2 MOBILE APPLICATIONS

Chargepoint Mobile App

The mobile application in Figure 38 developed by ChargePoint provides real-time status and availability of charge points ("Get the ChargePoint App | ChargePoint," n.d.). It can be connected to in-vehicle displays to perform smart charging. The charging status of EV constituting the expected time to complete charging, the rate of charging, the time remaining to finish charging, and the estimated fee are shown. From the customer's historical data and charging behaviour, it provides charging notifications.

It also provides information and notification regarding rush hours or popular timing based on behaviour analysis study on all connected EVs. It also provides a facility to manage RFID cards and transactions.

Figure 38: ChargePoint mobile application ("Get the ChargePoint App | ChargePoint," n.d.).

EV Juicenet App

EnelX provides a mobile application shown in Figure 39 to perform smart charging to reduce charging costs and indirectly support grid requirements. It provides an option of charge scheduling considering tariff structure. TOU structure is available as per the locational information provided in the app. TOU is a time-of-use price structure with different electricity prices according to the nature of demand (peak load, off-peak load). This interactive mobile application and web portal with charge scheduling saves the economic burden of the customer. In addition to the scheduling option, the app provides other options that cover technical and timely information about the current charging session ("emobility.enelx," n.d.).

Figure 39: EV JuiceNet mobile application ("emobility.enelx," n.d.)

Tesla, BMW charging, NisanConnect, ev.energy, EVGO, Plugshare, Evmatch, etc., are some additional smart charging mobile applications used commercially.

3.8.2 OPTIMISATION SOLUTIONS

EV charging is an emerging business, and it is directly related to the electricity grid and electricity cost. It initiates the need for optimization in the EV environment to minimize the charging cost, maintain grid stability, and maximise available energy utilisation. Commercially available smart-charging optimization solutions are listed below:

3.8.2.1 CHARGEPOINT ECO

ChargePoint provides a smart charging optimization solution named ChargePoint ECO ("ChargePoint ECO," n.d.) which facilitates users (industries, workplaces) to implement EV charging strategies as per business requirement. ChargePoint ECO has the capability of resource maximization and ecosystem integration. It optimizes the resources in real-time using available electrical capacity, available renewable energy, and battery storage. It optimistically determines the refueling need that used further to generate the charging schedule.

It follows industry open protocols and standards that help in accurate optimization considering all possible EV infrastructure data. The optimizer's dashboard shown in Figure 40 provides real-time charging information, which initiates various charging notifications for the customer. Customization of the optimizer is an attractive feature from the industry's business requirement perspective. Firms with different objects such as cost minimization and/or ancillary services can use this product.

Figure 40: Dashboard of Charge Point ECO ("ChargePoint ECO," n.d.)

3.8.2.2 EV SITE SOLUTION (EVSS)

ABB Ltd. Provides an EV site solution defined as an optimization energy management solution for EV charging stations ("EV Site Solution - EV Charging | Electric Vehicle Chargers | ABB," n.d.). It considers EVSE, solar, battery energy storage system (BESS), building automation, and grid while optimizing for a predefined objective. BESS are stacks of batteries to store the energy for later use. The primary optimization objective is to reduce charging costs and maximize charger utilization. It maintains grid parameters for growing EV charging demand by centralized energy monitoring and optimization. EVSS is beneficial for fleet control due to its capability of reducing cost and maximizing utilization of generation. Smart optimizer EVSS performs the optimization considering real-time site parameters and ensures EV charging allocation within the site's capability. This capability of the EVSS solution box, shown in Figure 41, eliminates the requirement of costly grid upgrades. It is scalable and can adapt to any future scaling of site and EV population growth. It also provides flexibility in allowing the EVSS to optimize for other objective functions.

Figure 41: EV site solution box ("EV Site Solution - EV Charging | Electric Vehicle Chargers | ABB," n.d.)

3.8.3 CONTROLLER

A load management controller is required in charging stations to manage energy distribution within the charging station. It coordinates power between the charging point of a charging station to maximize charging based on the real-time availability of power.

3.8.3.1 LOAD MANAGEMENT CONTROLLER

evMega provides a load management controller shown in Figure 42 ("Products | evmega," n.d.). It manages Level 1 and Level 2 charging load using different load management algorithms. Load management algorithms are classified as Grade 0, Grade 1, and Grade 2. Grade 0 is a queue management algorithm, whereas Grade 1 is a static load management algorithm. Grade 2 is a dynamic load management algorithm and performs real-time load management. The maximum allowed charger connections are 24 charger guns for 3-phase EVSE and 72 for 1-phase EVSE. It also supports clusters of chargers. For load management, it uses OCPP 1.6 open communication protocol. It can also connect using Wi-Fi or LAN for communication. It also has the feature of monitoring and displaying and uses RTU 485 Modbus for metering.

Figure 42: Load management controller ("Products | evmega," n.d.)

3.8.3.2 EVLINK LOAD MANAGEMENT SYSTEM

Schneider provides the EVlink series for EV charging products ("Catalog 2020 Electric vehicle charging solutions | EVlink | Schneider Electric," n.d.). EVlink load management system in Figure 43 performs monitoring and control and maximizing of EV charging. It is performed in real-time, considering the available capability of charging stations or a building. It performs load management for cost minimization and efficiency maximization. The EVlink load management system's primary function is to allocate power charging points and confirm centralization and availability to each charging point.

The management system is connected to charging points using LAN for internal communication. External communication is performed over Ethernet LAN or 3G/4G Modem and OCPP 1.6. It has an interactive user interface to allow remote start and stop of the charging session. The user also can reset and reboot the charging session. The dashboard provides the real-time charging status of each charging point and allows downloading of historical data. It manages up to 100 charging stations. With a decentralised and flexible architecture, the system can control up to 1000 charging stations in master/slave configuration. In decentralized and flexible architecture, it controls up to 1000 charging stations in master/slave configuration. The capacity of the number of charging points connected to the management system is dependent on the mode of operation (static and dynamic).

Master EVlink load management system (LMS) can manage 9 slave EVlink LMS and each slave EVlink can manage 100 charging stations. In fault situations, the management system manages load using two aspects as mentioned below:

- **Already consumed energy**

  In limited power availability conditions or load shedding conditions, the management system interrupts supply to the systems in descending order of charging stations with more energy consumption starting from its charging sessions.

- **Plug-in time**
  Management system interrupts the supply to EVs based on highest plug-in time of vehicles and favours lastly arrived EV.

3.8.3.3 VCHARM-CHARGING STATION MANAGEMENT

Figure 43: EV link load management system box ("Catalog 2020 Electric vehicle charging solutions | EVlink | Schneider Electric," n.d.)

It is a charging and load management software, a product of the company Vector ("vCharM | Charging Station Management System | Vector," n.d.). It intelligently coordinates charging points within charging stations. It is supported with OCPP 1.6, so it can easily work with any charging station. This makes vCharM an independent product from charging station manufacturers. This product is available and applicable in different variants for residential charging stations, commercial charging stations, EV fleet, and charge point operators. It also possesses interoperability because of OCPP without any other adoption as per the charging station's properties. The dashboard of vCharM shown in Figure 44 provides real-time optimization information.

Figure 44: Dashboard of vCharM- charging station solutions ("vCharM | Charging Station Management System | Vector," n.d.)

3.9 Commercially available charging stations

In this section a list of charging stations for AC and DC charging is provided. The market overview was presented as part of the PowerToDrive exhibition (PowerToDrive 2020). A comparison with the less extensive research of the Fraunhofer IEE showed, that this list is exhaustive with one constraints- the named companies are selling the products, however, they are not necessarily the manufacturer of the charging station. In addition, Table 4 provides some examples of available onboard chargers. The available information on onboard chargers is very limited, because the product is only sold to automotive OEMs.

Table 4: Commercially available charging stations for AC and DC charging

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
chargeIT mobility GmbH	E-Bus charging station	44 kW	–	3	type2	Input: 400V/63A, output: 3x230V/400V/63A	www.chargeit-mobility.com
	Hypercharger	22 kW	75-300 kW	3	CCS, Chademo, type2	–	www.chargeit-mobility.com
	Libreo One	22 kW	–	3	type2	Wall or ground mounted, input: 400V/50A, output: 230/400V up to 32 A	www.chargeit-mobility.com
	Plug&play charging box	33 kW	–	3	2xtype2	Wall or ground mounted, input: 400V/50A, output: 230/400V up to 32 A, each charging point max. 22 kW	www.chargeit-mobility.com
	Wall box	11 kW, 22 kW	–	3	type2	Wall or ground mounted, input: 400V/16A/32A, output: 3x230/400V max. 16A/32A	www.chargeit-mobility.com
ChargeX GmbH	Aqueduct	11, 22 kW	–	3	type2 socket, optional with cable type2	Plug and play modular expandable up to 8 charging points	www.chargex.de
Compleo Charging Solutions GmbH	charging system FLEET (Basic, Advanced)	3.7, 11, 22 kW	–	1, 3	charging cable (4m), type2 socket	Up to 60 charging points possible	www.compleo-cs.com
	CITO 240 & 500	22 kW	24 kW, 50 kW	1, 3	Charging cable, 3 in 1: Typ 2 | CCS | CHA	AC & DC in one station	www.compleo-cs.com
DAfi GmbH	Smartfox Pro and Car Charger app	1.3 kW/4.3 kW	–	1, 3	–	–	www.smartfox.at
Delta Electronics (Netherlands) B.V.	EV AC MAX charging station	7.4 kW, 11 kW, 22 kW	–	1, 3	type2	Input 230 VAC, 32 A or 400 VAC (3ph), 32A	emobility.delta-emea.com
	UFC 200 kW	65 kW	200 kW	3	CCS, Chademo, type2	Up to 1,000 V DC, up to 4 EV, CCS: 400 A, Chademo: 125 A, type2: 32/63 A	emobility.delta-emea.com
Designwerk Products AG	Mobile DC fast charger MDC22-450	–	20.8 kW	3	CCS type2, CCS type1, GB/T, Chademo	At CEE16 und CEE32 sockets or type-2-charger (output: 60 A, 270-450 V), also as wall box	www.designwerk.com
	Mobile DC fast charger MDC22-500	–	21 kW	3	CCS type2, CCS type1, GB/T (soon), Chademo	At CEE16 und CEE32 sockets or type-2-charger (output: 60 A, 250-500 V), also as wall box	www.designwerk.com
	Mobile DC fast charger MDC44-450	–	41.5 kW	3	CCS type2, CCS type1, GB/T, Chademo	At CEE16 und CEE32 sockets or type-2-charger (output: 120 A, 270-450 V)	www.designwerk.com
	Mobile DC fast charger MDC44-920	–	42 kW	3	CCS type2, CCS type1, GB/T (soon), Chademo	At CEE16, CEE32 and CEE63 sockets or type-2-charger (output: 120 A, 500-1,000V), also as wall box	www.designwerk.com
	Mobile DC fast charger MDC88-450	–	83 kW	3	CCS type2, CCS type1, GB/T, Chademo	At CEE16 and CEE32 sockets or type-2-charger (output: 240 A, 270-450 V)	www.designwerk.com

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
DiniTech GmbH	Charging cable NRGkick	22 kW	–	3	–	400 VAC, 6-32 A	www.nrgkick.com
E3/DC GmbH	Wall box easy connect	22 kW	–	3	type2	Charging currents 16/32A, 230/400 Volt AC	www.e3dc.com
eeMobility GmbH	eeBox	–	–	–	–	Charge at the company location	www.ee-mobility.com
EGS	Charging meter box	–	–	–	–	Mobile testing device for calibrating E charging stations	www.egs-metering.com
eLoaded GmbH	DC Cube	–	up to 420 kW	–	CCS, Chademo	Liquid cooling, up to 4 EVs	www.eloaded.eu
	DC Wall	–	up to 140 kW	–	CCS, Chademo	Liquid cooling, up to 4 EVs	www.eloaded.eu
	SupraCharger	–	up to 420 kW	–	CCS, Chademo	Liquid cooling, up to 4 EVs	www.eloaded.eu
Enercon GmbH	Fast charging system E-600	–	50-350 kW	3	CCS-Combo2, Chademo	400 VAC, up to 600 kW grid power connection	www.enercon.de
ENTRATEK GmbH	Power Arrow: AC charging station	2 x 22 kW	–	3	2xtype2	–	www.entratek.de
	Power Bay: DC charging station	–	60, 120, 180 kW	–	CCS, Chademo	Modular and compact design	www.entratek.de
	Power Capsule: DC wall box	–	30 kW, 60 kW	–	CCS/Chademo	Wall or stand mounting possible, concept for DC destination charging	www.entratek.de
EVBox	Wall box Elvi	3.7, 7.4, 11, 22 kW	–	3	type1, type2	–	www.evbox.de
Fastned	New generation of fast charging stations	–	350 KW	3	AC, CCS, Chademo	–	www.fastned.nl
Galaxy Energy GmbH	Charging station Slim/Ideal, wall box: Power	–	–	–	Schuko, type2	–	www.galaxy-energy.com
Greenpack mobile energy solutions GmbH	Swobbee	–	–	–	–	Battery changing system for small electric vehicles and gardening tools	www.swobbee.de
Hager Group	Witty home	22 kW	–	1, 3	type2, optional: Schuko	16/32A, optional RFID	www.hager.de
	Witty park	3.7-22 kW	–	1, 3	2xtype2, 2xSchuko	16/32A, RFID	www.hager.de
Heidelberger Druckmaschinen AG	Heidelberg Wallbox Energy Control	3.7-11 kW	–	1, 2, 3	type2 cable	5 m cable, integrated load management, metal casing	wallbox.heidelberg.com
	Heidelberg Wallbox Home Eco	3.7-11 kW	–	1, 2, 3	type2 cable	3,5/5/7,5 m cable, metal casing	wallbox.heidelberg.com
HUBER+SUHNER AG	RADOX HPC200 – charging cable system for DC fast charging	–	80 to 200 kW	–	CCS2	Charging cable system for 1,000 V/200 A continuous charging with signal wires for DC metering	www.hubersuhner.com
	RADOX HPC500 – charging cable system for DC high power charging	–	500 kW	–	CCS1, CCS2	Liquid-cooled charging cable system for 1,000 V/500 A continuous charging with signal wires for DC metering	www.hubersuhner.com

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
Ingeteam Power Technology, S.A.	Dynamic Load Management 2.0 (DLM 2.0) for INGEREV FUSION and RAPID	2.3-22 kW	up to 400 kW amps per amp	1, 3	type1, type2, Chademo, CCS	Supplied as standard in the FUSION and RAPID models.	www.ingeteam.com
	INGEREV FUSION STREET AND FUSION WALL	2.3-22 kW	–	1, 3	Schuko, type1, type2	Maximum input current 64 A (32 A + 32 A)	www.ingeteam.com
	INGEREV RAPID 50 (Duo, Trio)	43.5 kW (Trio)	50 kW	3	type2, Chademo, CCS	1-3 EVs, Ethernet, WLAN, 3G, 50-500 VDC/125 A	www.ingeteam.com
	INGEREV RAPID ST 200 & ST 400	–	up to 200 kW & 400 kW	3	Chademo, CCS	Charge current: 400A/500V or 200A/1000V for ST200 kW & 400A/1000V or 500A/500V * limited by the available CCS connectors	www.ingeteam.com
innogy eMobility Solutions GmbH	Charging station eStation BTC High Power Charger 200	–	150/350 kW	–	CCS-2, Chademo	2 EVs: 150 kW each or 1 EV: 350 kW, power sharing if 2nd EV is connected (50 kW increments)	www.innogy-emobility.com
	Charging station eStation smart/ smart RFID	2x22 kW	–	3	type2	2 EV, smart phone App, RFID	www.innogy-emobility.com
	Wall box eBox professional	3.7-22 kW	–	3	type2	Smart phone app, RFID, plug&charge, LAN, WiFi, bluetooth and mobile data network connectivity, innogy eOperate can be activated	www.innogy-emobility.com
	Wall box eBox smart	3.7-22 kW	–	3	type2	smart phone app, WiFi, bluetooth, RFID	www.innogy-emobility.com
	Wall box eBox touch	3.7-22 kW	–	3	type2	Smart phone app, RFID, plug&charge, LAN, WiFi, bluetooth and mobile data network connectivity, 5" touch screen, innogy eOperate can be activated	www.innogy-emobility.com
INTIS GmbH	INTIS WPT: commercial lorrys	–	20, 40 kW	3	induktiv, optional: Typ2, CCS, Chademo	48 V, 80 V or HV, up to 400 A charging	www.intis.de
	INTIS WPT: inductive charging	–	11-50 kW	3	induktiv, optional: Typ2, CCS, Chademo	Multiple 50 kW modules for bigger trucks	www.intis.de
	INTIS WPT: small power	–	80-1,000 W	1, 3	induktiv	For e-bikes, scooter, rollers, robots	www.intis.de

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
Juice Technology AG	Accelerator PHASER	5.8 kW	–	1	type1, type2	1-phase charging accelerator in combination with Booster 2, input (3-ph) 14.5 A, output (1-ph) 25 A, IEC 62752, 62196, 61851, EMC, RoHS, IP65	www.juice-technology.com
	Charging station TOWER 2	11-22 kW	–	3	type2	All common billeting systems, NFC, RFID, optional 2 sockets, calibrated meter, Smart-Juice-Module for load management, FI A-EV, IP54, IEC 62196, 61851-1, CE, EMC, RoHS	www.juice-technology.com
	Charging station ULTRA	–	75-300 kW	3	CCS2, CCS1, type2 socket, Chademo	RFID, NFC, credit cards, IP 54, EN61851-23, DIN 70121, ISO 15118, RFID system: ISO/ IEC 14443A/B, ISO/ IEC 15639, GSM/CDMA, T-Ethernet	www.juice-technology.com
	Mobile station BOOSTER 2, Pro	1.4-22 kW	–	1, 3	type1, type2	Up to 32 A each phase, adapter set and mode 3, Pro version: adapter EV, IEC 62752, 62196, 61851, mode 2/3, EMC, RoHS, IP67, RCD DC 6 mA, AC/DC 30 mA	www.juice-technology.com
	Mobile station DIRECTOR 2	–	22 kW	3	CCS 2, type2 socket, Chademo	IP 54, EN 61851-23, DIN 70121, ISO 15118, Combo 2, Chademo 0.9.1, Ethernet, GSM/ GPRS/UMTS or powerline	www.juice-technology.com
	Wall box CHARGER 2	1.4-22 kW	–	1, 3	type1, type2	Calibrated meter, Smart-Juice-Module for load management, all common billeting systems (incl. credit cards), IEC 62752, 62196, 61851 - mode 3, EMC, RoHS, IP65, RCD DC 6 mA, AC 30 mA	www.juice-technology.com

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
KEBA AG	KEBA KeContact P30 wall box	3.7-22 kW	–	1, 3	type1, type2	MID-certified, Ethernet, RFID, WLAN, USB, OCPP	www.keba.com
Kreisel Electric GmbH & Co. KG	CHIMERO HPC&EES	22 kW	150 kW	3	type2, CCS	–	www.kreiselelectric.com
LappKabel U.I. Lapp GmbH	Charging plug Design and Heavy Duty (BMW)	7.4-22 kW	–	3	–	Fast charging cable Helix 20/32 A	www.lappkabel.de
MAHLE GmbH Corporate Startup chargeBIG	Scalable charging system	2.3-7.2 kW, 22 kW	–	1, 3	type2	Max. 36 charging points per system, one charging point up to 32 A single phase/ three phase, IP55, charging pillar and/or wall mount	www.chargebig.com
MENNEKES Elektro- technik GmbH & Co. KG (Distributor: Parkstrom)	Wall box Amtron, charging station Amedio, charging gear PowerTOPXtra	3.7, 11 or 22 kW	–	3	type1, type2	With charging App, software backend, conform with German Eichrecht	www.chargeupyourday.de
neoom group GmbH	BOOGIE	2 x 22 kW	–	3	type2	–	www.neoom.com
neoom group GmbH	BOXX	22 kW	–	3	type2	–	www.neoom.com
neoom group GmbH	WHIZZY	11 kW	–	3	type2	–	www.neoom.com
Nidec ASI s.p.a.	Ultra Fast Charger	–	160 kW	–	CCS, Chademo	Grid power: only 50 kW	www.nidec-industrial.com
Phoenix Contact E-Mobility GmbH	Charging cables, charging sockets and charging controllers	up to 22 kW	up to 500 kW	1, 3	type1,type2,CCS type1/type 2 and GB/TAC/DC	Scalable components for each application, adapted to performance and functionality	www.phoenixcontact.net
PION Technology AG	Charging station advancedPION	11, 22 kW	–	3	type2	OCPP 1.6 or PION backend	www.pion-ag.com
PION Technology AG	Charging station publicPION	11, 22 kW	–	3	type2	OCPP 1.6	www.pion-ag.com
PION Technology AG	Charging station purePION	11, 22 kW	–	3	type2	No backend	www.pion-ag.com
PION Technology AG	Charging station smartPION	11, 22 kW	–	3	type2	OCPP 1.6 or PION backend	www.pion-ag.com
PION Technology AG	Wall box WAVEadvanced	11, 22 kW	–	3	type2	OCPP 1.6 or PION backend	www.pion-ag.com
PION Technology AG	Wall box WAVEpure	3.7, 11, 22 kW	–	3	type2	No backend	www.pion-ag.com
PLUG'n CHARGE GmbH	Car park system Premium (3 charging points)	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	Charging station Basic Plus	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	Charging station Premium	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	E-Polly Basic Plus	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	E-Polly Premium	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	Ecar park system Basic Plus (3 charging points)	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	Wall box Basic Plus (cable or socket)	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
PLUG'n CHARGE GmbH	Wall box Premium Kabel	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
PLUG'n CHARGE GmbH	Wall box Single Premium	3.7, 11, 22 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
	Wall box Twin Premium	3.7, 11 kW	–	3	Typ2	400 VAC, RFID, Smart Meter, RS485	www.plugncharge.de
Schneider Electric GmbH	EVlink DC wall box	22 kW	up to 24 kW	3	CCS, Chademo, type2	CCS only or CCS + Chademo or CCS + Chademo + type2	www.schneider-electric.de
	EVlink parking lot 2	22 kW	–	3	2 x type2 or type2 + TE	Optional with Schuko socket instead of type2	www.schneider-electric.de
	EVlink parking lot 3	22 kW	–	3	2 x type2	Optional compliant with legal requirements (parking lot 3)	www.schneider-electric.de
	EVlink wall box G3	3.7, 11, 22 kW	–	1, 3	1 x type2 (optional cable with type1)	16/32A, optional with fixed cable 4.5 m	www.schneider-electric.de
	EVlink wall box G4	3.7, 11, 22 kW	–	1, 3	1 x type2 (optional cable with type1)	16/32A, optional with fixed cable 4.5 m	www.schneider-electric.de
Sedlbauer AG	E-Tower	up to 2x22 kW	–	3	Typ2	1 or 2 EVs	www.sedlbauer.de
	Juice Booster 2 (distributor)	22 kW	–	3	EV: type2, grid: several adapters	–	www.sedlbauer.de
	SlimBox	3.7, 11, 22 kW	–	3	type2	–	www.sedlbauer.de
	SlimBox E	3.7, 11, 22 kW	–	3	type2, Schuko	Type2 or Schuko charging at same time	www.sedlbauer.de
Siemens AG	Wall box VersiCharge	4.6, 7.2, 22 kW	–	1, 3	type1, type2	DC-FI integrated, IP56, RFID reader	new.siemens.com
SMA Solar Technology AG	EV Charger 7.4/22	1.3-7.4/22 kW	–	1, 3	type2	With Sunny Home Manager and SMA Energy App	www.sma.de
SolarEdge Technologies GmbH	Solar inverter with integrated wall box	7.6, 9.6 kW	–	1	–	32 A/40 A, with solar inverter HD wave	www.solaredge.com
sonnen GmbH	sonnenCharger	22 kW	–	1, 3	type2	With sonnenCommunity or sonnenFlat only	www.sonnen.de
SSL Energie GmbH	Pay-Charge	3.7-22 kW	–	1, 3	type2	16/32A, socket wirh LED	www.ssl-energie.de
	SP-Charge	max. 22 kW	–	1, 3	type2	Configurable current: 10A, 13A, 16A, 20A, 25A, 32A, 5 m cable with plug type2	www.ssl-energie.de
Stäubli Electrical Connectors GmbH	Automatic Rapid Charging Solution QCC	–	up to 1,200 kW	3	customized	Automatic charging of EVs (AGV, busses, trucks, boats etc.)	ec.staubli.com
StreetPlug B.V.	Charging station beyond street level	3.6 kW, 11 kW, 22 kW	–	1, 3	type2, Schuko	Load managemenr, charging via app, charging card or remote control	www.streetplug.nl
Tesla Motors Netherlands BV	Supercharger	145 kW	–	–	own standard	480 VDC	www.tesla.com

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
ubitricity Gesell- schaft für verteilte Energiesysteme mbH	SimpleSocket Chelsea	3.7-4.6 kW	–	1	type2	Polycarbonate, IP55	www.ubitricity.com
	SimpleSocket P11	11 kW	–	3	type2	Single or dual bollard with ram protection, integrated DC residual current device, load management capable	www.ubitricity.com
	SimpleSocket W11	11 kW	–	3	type2	Wall mounting inside and outside, Integrated DC residual current circuit breaker, load management capable	www.ubitricity.com
	SmartCable 20A, single phase	4.6 kW	–	1	type1, type2	Automatic authentification, charging cable with mobile metering function	www.ubitricity.com
	SmartCable 20A, triple phase	13.8 kW	–	3	type2	Automatic authentification, charging cable with mobile metering function	www.ubitricity.com
wallbe GmbH	Pro charger	3.7-22 kW	–	1, 3	type2 or Schuko socket, optional: type1/type2 cable	230 VAC (16 A), 400 VAC (32 A)	www.wallbe.de
Wallbox Chargers SL	Commander 2	7.4 kW, 22 kW	–	1, 3	type1, type2	Connectivity: Wi-Fi/Ethernet/ Bluetooth/3G/4G, RFID/ App/PIN-Code identification, modular current from 6 A to 32 A	www.wallbox.com
	Copper SB	7.4 kW, 11 kW, 22 kW	–	1, 3	type1, type2	Connectivity: Wi-Fi/Ethernet/ Bluetooth/3G/4G, RFID and app identification	www.wallbox.com
	Pulsar Plus	7.4 kW, 11 kW, 22 kW	–	1, 3	type1, type2	Connectivity: Wi-Fi/Bluetooth, App identification, modular current from 6 A to 32 A	www.wallbox.com
	Quasar	–	7.4 kW	–	CCS, Chademo	Bidirectional charger, modular current from 6 A to 16 A, connectivity: Wi-Fi/ Ethernet/Bluetooth/3G/4G, RFID or app identification	www.wallbox.com

Company	Product	AC Power	DC Power	Phases	Sockets | Plugs	Remarks	Data Sheet | Information
Walther-Werke Ferdinand Walther GmbH	ECOLECTRA 250	up to 22 kW	–	3	type2	System capability, load management, one or two charging points, master/slave system solution, OCPP 1.6	www.walther-werke.de
	ECOLECTRA 600	up to 22 kW	–	3	type2	Standalone solution, optional One Touch-Display, OCPP 1.6	www.walther-werke.de
	EVOLUTION 350	up to 22 kW	–	3	type2	System capability, load management, master/slave system solution, OCPP 1.6	www.walther-werke.de
	Wall box basicEVO	up to 11 kW	–	1, 3	type2	Charging cable 5 m, Plug'n Charge	www.walther-werke.de
	Wall box systemEvo	up to 22 kW	–	1, 3	type2	One or two charging points, master/slave system solution, OCPP 1.6	www.walther-werke.de
	Wall box varioEVO	up to 11 kW	–	1, 3	type2	Charging cable 5 m, Plug'n Charge, load management	www.walther-werke.de
Webasto Thermo & Comfort SE	Webasto Live	3.7-22 kW	–	1, 3	type2	16/32A, 4,5 m & 7 m cable, ISO 15118 (PnC), OCPP 1.6, RFID-DESFire, EEBus, 4G embbedded Sim (eSim)	www.webasto-charging.com
	Webasto Pure	3.7-22 kW	–	1, 3	type2	16/32A, 4,5 m cable	www.webasto-charging.com
Wirelane GmbH	Double pole	3.7-22 kW	–	1, 3	type2	Eichrecht or MID certified, ISO 15118 ready, FI-Typ A, FI-Typ B per measuring current transformer	www.wirelane.com
	Pillar or wall mounted	3.7-22 kW	–	1, 3	type2	Eichrecht or MID certified, ISO 15118 ready, FI-Typ A, FI-Typ B per measuring current transformer	www.wirelane.com
	Single pole	3.7-22 kW	–	1, 3	type2	Eichrecht or MID certified, ISO 15118 ready, FI-Typ A, FI-Typ B per measuring current transformer	www.wirelane.com

Table 5: Examples of commercially available onboard chargers

Company	Name	Charging Power	Type
Bosch	Charger-converter	7.2 kW (1-ph, 2-ph)11 kW (3-ph)	Charger with integrated Low-Voltage Battery DC/DC Converter
Brusa	ON-Board Charger NLG664	22 kW (3-ph)	Bidirectional, 400V battery
Brusa	ON-Board Charger NLG667	22 kW (3-ph)	Bidirectional, 800V battery
Innolectric	On-Board Charger	22 kW (3-ph)	DC charging included
Xepics	XP Power+	22 kW (3-ph)	Galvanically isolated

3.10 Smart Chargers in India and its capabilities

In India, smart charging is yet to be fully implemented because of the early transition stage and lower EV penetration percentage. However, to take care of the future requirements of EV charging, chargers are already smart enough to allow smart charging with power modulation. There are many smart chargers available from different manufacturers in India, as mentioned in Table 6. These smart chargers are identified based on the presence of a control pilot pin in the connector. India has adopted various connectors for AC and DC power transfer for EV charging. IEC 60309 is the AC connector with three pins without a control pin and hence, cannot perform smart charging using real dynamic power modulation. So, the charger with an IEC 60309 connector is not capable of executing smart charging. The IEC 62196 or Type 2 or Mennekes connector is also allowed per Indian charging standards, and it can perform smart charging. CHAdeMO, CCS, and GB/T are the DC connectors capable of executing smart charging. Table 5 presents the summary of connectors regarding the capability to perform smart charging.

India has adopted various connectors for AC and DC power transfer for EV charging

Table 6: Capabilities of various connectors

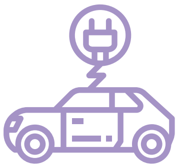
Connector type	Name of connector	Capability to perform smart charging
AC	IEC 60309	❌
	IEC 62196/type 2/Mennekes	✅
DC	CHAdeMO	✅
	CCS	✅
	GB/T 20234	✅

❌: Dumb connector, ✅: Smart connector

These smart chargers can follow and implement dynamic variations in delivering power to the vehicle. It can vary the supply power to the EV by generating modulating power commands from the aggregator. This power modulation for smart charging is carried to maintain generation-demand balance in the system at every point in time. Smart charger facilitates the basic requirement of communication connectivity in a controlled charging scheme. Communication is established between smart chargers and other entities in the EV ecosystem by using different standards and protocols. The compatibility of chargers to OCPP and OSCP allows smart charging communication.

Chargers available in India are required to comply with the Ministry of Power (MoP) guidelines. To compliment the regulation, policies are providing incentives in purchasing EVs and chargers thus reducing the capital cost of the charger, as mentioned in Table 6. From the aspects of communication connectivity, all the smart chargers available in the market complies OCPP

In India, smart charging is yet to be implemented with full capacity because of the early transition stage and lower EV penetration percentage.



1.5 and higher version, which will help in smarter communication and controlled charging in the near future. Chargers available in the market follow either Bharat AC001, DC001, or other charger protocols, such as CCS and CHAdeMO. In addition to this, the market has sufficient availability of types of connectors approved by the Ministry of Power in Charging Infrastructure Regulation.

By focusing on the availability of smart chargers, the Indian market has seen rising growth in the adoption of smart chargers compared to dumb chargers. In support of smart chargers, various smart applications like cloud-connected charging networks and mobile applications are also growing in the Indian EV ecosystem.

3.10.1 EV CHARGERS, TECHNICAL SPECIFICATIONS, AND MANUFACTURERS IN INDIAN MARKET

Table 6 provides the technical specifications and cost of dumb and smart chargers available in India. The table also includes information on charging station manufacturers and respective EV categories supported by the particular charger.

Table 7: Technical specifications and cost of commercially available EV chargers in India

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
1	Delta India	"AC Charger Slim II"	AC charger	200-240V Single Phase Max 30A	200-240V Single phase Max 30A	ICE62195-2 Type 1 Type 2 GB/T: Subject to the region or country standard	-	-	-	Mode 1		2,3,4W
		AC Mini plus	AC charger	200-240V Single Phase Max 30A	200-240V Single phase Max 30A 7.4kW max	1.ICE62196-2 Type 1, Type 2, GB/T" 2.ICE 62196-2, Type 2 Socket	-	3G Wi-Fi for remote access	95%	Mode 1	89,200/-	2,3,4W
		AC Max	AC charger	-	EVAAU 11.5-19.2kW EVAAE 7.4,11,22kW EVAAG 7.4,11,22kW	1.SAE SJ1772 2.ICE62196-2 Type 1, Type 2, GB/T"& ICE62196-2, Type 2 Socket&. ICE62196-2, Type 2 Socket with shutter 3.GB/T20234-1/2	-	1.RFID and ISO 15118 authentication for user management 2.ethernet, Bluetooth LAN Cellular 3.OCPP compliance enables back end system integration upgradable to OCPP 2.0	-	Mode 2 Mode 3	1.30Lakhs/-	4W
		DC (150DC Ultra-Fast EV Charger	CCS + CHademo + AC	-	1.150 kW DC charging capacity in total, CCS up to 100 kW, CHAdeMO up to 63 kW 2. 43 kW charging point with -Type 2 plug, 22 kW charging point with Type 2 socket.	CCS, CHAdeMO and Type 2 plug	1.2 DC charging points 2.2 AC charging points	Communication: -Network Connectivity: Ethernet,3G, GPRS -Protocol: OCPP1.6	94%	Mode 4	1.50 Lakh/-	4Wheeler, Bus
		DC Quick EV charger	CCS+ CHademo	-	150kW	-	2 DC Charging point	Ethernet,3G, GPRS Protocol: OCPP1.6 RFID card reader for user authentication	94%	Mode 4	19.55 Lakh/-	4-Wheeler, Bus
		DC EV Charger GB/T	DC	-	120kW	-	-	OCPP/Delta Proprietary 3G/4G, Wi-Fi (Optional)	94%	Mode 4	-	-
		DC Wall box EV charger	(CCS and CHAdeMO compliance)	1.240-270vAC, 50Hz, Single phase 2.480vAC, 50Hz, Three-phase 3.208vAC, three phase	1.DC O/P 25kW,200-500vDC, 65A Max 2.50-500,60A Max, 25kW	1.SAE SJ1772 2.CHAdeMO	2	3G/4G, Ethernet (Optional)	94%	Mode 4	1.26Lakhs/- 9.25Lakhs/- for 25kW	-
		BHARAT DC 001	DC Charger	3 Phase, 415 Vac, (373 ‾ 440 Vac)	15kW,200 A Max	GB/T 20234.3	2	Charger & Vehicle: CAN Communication Charger & CMS: Protocol: OCPP 1.6 (Open Charge Point Protocol) Interface Network Connectivity: Ethernet, 2G/3G/4G, Wi-Fi (Optional)	94%	Mode 4	2 Lakh/- (15kW) 4.50 Lakh/- (30kW)	4- Wheeler

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
		DC Charger city	DC Charger	-	1.DC 50kW, 2.AC 22kW, 50-1000vdc, 125A Max,50-1000vdc, 125A Max, AC 22kW,400 VAC.32A 2.50kW,50-1000vdc, 125A Max, 50-1000vdc, 125A Max 3.DC 100kW, 50-1000vdc, 125A Max,50-1000vdc, 200A Max,AC 22kW,400 VAC.32A 4.100kW,50-1000vdc, 125A Max, 50-1000vdc, 200A Max	1.CCS .CHAdeMO, IEC 62196-2. . Type 2 Socket 2. CCS 1. CHAdeMO 3.CCS 2. CHAdeMO, IEC 62196-2. 3.Type 2 Socket 4.CCS 1. CHAdeMO	-	RFID, credit card and ISO 15118 user identification OCPP and network connectivity enables system integration	>94%	Mode 3 Mode 4	-	4-Wheeler, Bus
2	Brightblu	Brightblu Charger	AC Charger	220V@32A, 50Hz/60Hz	7.2kW	TYPE 2	-	RFID, Mobile application, RFID card type 1444	-	Mode 3	40,000-1,00000/-	2,3,4-Wheeler
3	Aeidth Technologies	E-URJA	BharatAC 001	3 Phase, 415 Vac (374~440Vac)	230Vac, 50Hz, 3.3KW Max. per Output	IEC 60309, (3 PIN Female Connector)	3-Port	Protocol: OCPP Interface: Ethernet (2G/3G/4G optional)	-	-	-	-
		IEC 62196	AC TYPE-2 charger	-	Up to 40 kW Max Power.	Releasing soon as per the website					-	-
		DC	CCS COMBO 2 TYPE	-	10kW-75kW and above						-	-
		TYPE-DC	DC charger CHADEMO	-	10kW-75kW and above.						-	-
4	ABB India	Terra AC wall box	AC Type 1 Type 2 charger	-	Single-phase up to 7.4kW/32A 3Phasse up to 22kW/32A UL ratings up to 7.7 kW / 32 A	Type 2 socket with or without shutter Type 1 or type 2 cable. The cable can be wrapped around the charger	1output	1. OCPP 1.6 2.RS485/P1 for connection to energy meter 3. Wi-Fi, Ethernet (RJ45), Bluetooth, RS485, 4G / 3G 4. User authentication through ABB RFID card (1 included) or app	-	Mode 2	1.30 Lakh/-	2,3,4 Wheeler

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
		Terra DC Wall box 1.DC Wallbox 24 kW IEC version 2.DC Wallbox 24 kW UL version 1-phase 3.DC Wallbox 24 kW UL version 3-phase	DC charger 1. Type 4: CCS 2, CHAdeMO 2. Type 4: CCS 1, CHAdeMO 4. Type 4: CCS 1, CHAdeMO	Input Voltage: 1. 3-phase 400 V AC +/- 10 % 2. 208 … 240 V AC two-wire +/- 10% 3. 3 phase 480 V AC +/- 10 % Input Current: 1. 3-phase, 40 A 2. 100 A 3. 3 phase, 40 A	1. 0 … 22.5 kW, 24 kW (peak) 2. 19.5 kW - 208 V, 22.5 kW - 240 V 3. 0 … 22.5 kW, 24 kW (peak)	-	1. Standard: single output CCS2 Optional: dual output CHAdeMO + CCS 2 2. Standard: single output CCS10 ptional: dual output CHAdeMO + CCS 1 3. Standard: single output CCS10 ptional: dual output CHAdeMO + CCS 1	Communication protocol: 1. OCPP 1.5 / 1.6 / 2.0 2. OCPP 1.5 / 1.6 / 2.0 3. OCPP 1.5 / 1.6 / 2.0 User Authentication: 1. RFID (ISO 14443 A + B to part 4 and ISO/IEC 15693 Mifare, NFC, Calypso, Ultralight, PayPass, HID; and more). 2. On-screen PIN code authentication 3.Plug & charge (ISO 15118)	95%	Mode 4	1.25 Lakh/	-
		Terra DC fast charger Terra 54 Terra 94 Terra 124 Terra 184	-	AC Input Voltage 480Y / 277 VAC +/- 10% (60 Hz)	1. 50 kW continuous 2. 90 kW continuous 3.120 kW or 60 kW x 2 continuous 4. 180 kW or 90 kW x 2 continuous1. DC O/P Voltage: Teraa 54: CCS-1: 200 - 500 VDC CHAdeMO: 50 - 500 VDC HV version: 200 - 920 VDC For rest 3 CCS-1: 150 - 920 VDC CHAdeMO: 150 - 500 VDC DC O/P Current:- Terra 54 -125A For rest 3:- CCS-1: 200 A; CHAdeMO: 200 A (125 A optional)	-	-	Charging protocols :CCS1, CCS2 and CHAdeMO 1.2 RFID system: ISO/IEC 14443A/B, ISO/IEC 15393, FeliCa™ 1, NFC reader mode, Mifare, Calypso, (option: Legic) Network connection GSM/3G/4G modem; 10/100 Base-T Ethernet Communication: OCPP 1.6 Core and Smart Charging Profiles; Autocharge via OCPP	95%	Mode 4	75000/- for 5kW	2,3,4 W
5	Indegreen Technologies Pvt.Ltd	DC Charger	-	-	15kW	-	3-Pin	-	-	Mode 4	75000/- for 5kW	4W

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
6	Evlion Technologies Pvt Ltd	Fast Charger	Type 2	I,P Current: 66A I/P Power: 46KVA I/P Frequency: 50Hz	43.5kW Output Voltage Range 400V +-10 % Max. Output Current 3x63A	IEC 62196 Model 3,	-	-	96%	Mode 2 Mode 3	75000/- for 5kW	-
		Bharat AC001	AC charger	Input Voltage 415V (374-440V AC) Input Frequency 50+- 1 Hz	3.3KW Max. Output Voltage 230V AC Output Frequency 50 Hz Output Power 3.3KW Max. Output Current 15 Amp	IEC60309 (3 Pin Female Connector)	3	User Authentication OCPP	-	Mode 1	50,000/-	2,3,4 Wheeler
		Bharat DC 001	DC charger	Input Voltage 415V AC, 3 Phase, 5 Wire System (3Ph+N+E)	Output Current Max. 200 Amp Output 1 Rating 15 kW Max. at 48V/60V/72V	CCS2.0 / CHADEMO / GB/T 20234.3	1	-	>92 %	Mode 2	3 Lakh/ -	4- Wheeler
7	Powertron	PIPL-100KEV EV Car Charger	-	Input Voltage 3 Phase Frequency (HZ) 55 Hz	Output Voltage DC 150V	-	2	-	-	Mode 4	12.60 Lakh/-	4- Wheeler
		PIPL-25KEV Vehicle Car Charger	-	Frequency 50 Hz	Output Voltage DC 100V	-	-	-	-	Mode 4	-	-
		EV Charger	DC Charger	Input Voltage AC 380V	Output Voltage Max. DC 750V Rated Power 120 kW	-	-	-	-	Mode 4	19.46 Lakh/-	-
8	Magenta power	Charge grid series	Fast Charger Charge grid bolt	-	-	-	-	-	-		5.55lakhs/-	-
			Charge grid Polo	Single-phase, 230 Vac 50Hz	7.2 kW,32A	Type 2	1	Charger & CMSOCPP 1.6 (upgradable to OCPP2.0) Network Connection Sim: 2G/3G/4G, Ethernet, Bluetooth	-	Mode 3	2.75 Lakh/-	2,3 and 4-Wheeler
			Ultra AC 001	415, 3phase	230Vac, Single phase, 15A each	IEC 60309	3	OCPP 1.6J Ethernet, 2G,3G Wi-Fi optional	-	-	63,200/ Piece	-
			DC Fast Charger	415, 3phase	30-80kW, 125/200A, 90-120kW, 200-750Vdc, 200A max 150-200kW, 300A max	Type 2	1/2 1/2 2	PLC Based communication as per DIN 70121 OCPPV1.6 10/100 base T ethernet, Optional; GSM. ISO/IEC 14443 RFID User Authentication	95%	Mode 4	12,00000/-	4 Wheeler, Bus

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
9	FORTUM	-	DC 001 Charger	-	15-20kW	-	-	-	-	Mode 4	-	2,3,4W
		-	DC rapid charger	-	50kW	CCS/CHAdeMO	-	-	-	Mode 4	-	4-W
10	Exicom	Type-2 AC Charger (Compact)	AC Type 2 charger	270Vac	3.3kW	IEC62196-2, Type 2	-	OCPP 1.6J complaint IP54 - Designed for indoor or outdoor applications	-	Mode 1	-	All Type 2 compatible vehicles
		Type-2 AC Charger	AC Type 2 wallbox charger	150-270Vac	3.3kW, 7.5kW, 11kW and 22kW	IEC 612196-2	-	Optional RFID for user authentication and network connectivity for remote management, managing energy costs etc. OCPP 1.6J complaint IP54 - Designed for indoor or outdoor applications	-	Mode 2	-	All Type 2 compatible vehicles
		Multi standard 30-200kw	CHAdeMO, CCS and Type 2 AC,	340-520 Vac	1.22kW 2.60kW 3.60kW O/P Voltage 1.340VAC-520VAC 2.200 -750 Vdc 3.200 – 750 Vdc o/p Current 1.32A 2.125A 3.125A	1.CHAdeMO 2.CCS T 3.Type 2 AC,	1.1xAC 2.1xDC 3.1xDC	1.ISO/IEC 14443A RFID based authentication 2.10/100 Base-T Ethernet, 4G/3G modem (optional)	-	-Mode 3 Mode 4	-	All types of vehicles
		GB/T 30-200kw	GB/T with 20234.3 compliance	-	1.30-80kW 2.90kW - 120kW 3.150kW - 200kW O/P Voltage 200 – 750Vdc O/P Current 1.25A/200A 2.200A 3.200A	GB/T with 20234.3 compliance	1.1 / 2 DC 2.1 / 2 DC 3.2 DC	1.ISO/IEC 14443A RFID based authentication 2.10/100 Base-T Ethernet, 4G/3G modem (optional)	-	Mode 4	-	All types of vehicles, from entry-level passenger cars to heavy commercial vehicles
		Quick charger	-	415Vac	6000W above 185Vac (6kW system) 9000W above 185Vac (9kW system) Output voltage, nominal 42 - 58Vdc Maximum output current 125A (6kW system) 187A (9kW system)	SBS-75X Connector	1 x DC	B/w EVSE & vehicle: CAN based communication	-	Mode 4	-	passenger cars, E-rickshaws, E-Autos
		Ultima 48V/2kW	-	90 - 300Vac	22A (max) 42 - 58Vdc	Plug: SBS-75X	3 pin Indian plug	CAN Bus	~94%	Mode 2	-	E-rickshaws, E-autos and E-scooters.

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
		Ultima 48V/1.1kW	-	90 - 300Vac	42 - 58Vdc 22A (max)	Plug: SBS75-X	3 pin Indian plug	CAN Bus	Peak 94%	Mod e2	-	E-rickshaws, E-autos and E-scooters
		BHARAT EV /15kW/ 20kW	GB/T with 20234.3 compliance	460Vac	15kW (single gun) / 20kW (double gun) 40 – 100Vdc 200A	GB/T with 20234.3 compliance	1/ 2 DC	10/100 Base-T Ethernet, 4G/3G modem (optional)	-	Mode 4	1.30 Lakh/ Unit	2W to 4W
11	Plugngo -	BHARATAC -001	AC Charger	Input Voltage (AC) 3 Phase 415 Vac(374~ 440Vac) Input Frequency 50±1Hz	Output Current Max. 15 Amp, per output Output Rating 230Vac, 50Hz, 3.3KW Max. per output	IEC 60309, (3 Pin Female Connector)	3	User Authentication OCPP Charger and CMS Protocol: OCPP (Open Charge Point Protocol) Interface: Ethernet, 2G/3G/4G	-	Mod e1	-	2,3W
		EVMDCFCLV-18kW Combo	DC Charger	AC Input 3 Phase 4wire, AC 380~480V (Standard) AC Input 0.99	Max 60Vdc/160A @each output Max 60Vdc/80A @each output Max 230Vac/16A @each output	-	2 Nos of SBX 175 4 Nos of SBX 75 3 Nos of Industrial Plug	-	-	Mode 4	-	4W
		BHARATDC -001	DC Charger	AC Input 3 Phase, 415 Vac, (374~440V) AC Output Power 10 kW/15 kW/5 @ 40V/60V/72V	Max. 200A	GB/T 20234.3	-	Protocol: OCPP 1.6 (Open Charge Point Protocol) Interface: Ethernet, 2G/3G/4G	-	Mode 4	-	3,4W
		DC 30 KW	-	Input Voltage ≥ 94% Input Frequency 50Hz, ± 5Hz	DC Output Voltage Rating 48V/60V/72V DC Power Rating 30kW	Output connector with GB/T (Bharat DC001)	2	B/w EVSE and Vehicle Can based communication as per AIS - 0138-2 B/w Charger and Central Server OCPP v1.6 - 10/100 - T Ethernet (Standard)/ Optional GSM Model (4G Fallback 3G)	-	Mode 4	-	-

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
		DC 50 KW	-	Input Voltage Range 400 V +/-10% (50 Hz or 60 Hz) Max rated input current & power CJG, CG:143 A, 98 kVA	-	-	-	RFID System: ISO/IEC 14443A/B ISO/IEC 15393 Network Connection GSM / 3G Modem 10/100 Base-T Ethernet IP54 GSM / 3G Modem 10/100 Base-T Ethernet	-	Mode 4	-	-
12	Ensto	Home Charging eFiller	3x16A IP44 Type2	Type of current: AC, 50Hz	≤ 230 V	-	-	-	-	Mod e1	-	-
		Public Charging	-	Nominal current: 3x32A Rated voltage: ≤ 230 V	-	-	-	-	-	Mode 2	-	3,4W
		Ensto one	Type 2 -socket as a default. Models with fixed Type 2	3.6kW (16A) or 7.4kW (32A)					-	Mode 2		
13	Semaconnect	-	AC charger J1772 plugs for all EV	208/240V, center grounded, 60Hz supply	30A maximum, 7.2kW@240VAC	SAE J1772	-	Commercial CDMA or GPRS cellular network 128-bit AES Encryption ISO 15693 (iCLASS), ISO14443 (MIFARE, DESFIRE)	-	Mode 2	-	-
14	Zevpoint	Commercial charger	AC charger	400V AC 50/60 Hz	22 KW 32 A (3 Phase)	IEC 62196-2, Type II	-	3G (GPRS) ISO 14443A & ISO 15693 5m Cable Type 2 Female Plug OCPP 1.6 (with GSM)	-	Mode 2	-	-
		DC Charger	-	-	Up to 350kW	-	-	-	-	Mode 4	-	-
15	Chargemygaadi	DC Charger 75-150kW	DC chargerCCS1 AND CCS2	-	75-150kW 150-1000V	-	-	GSM/CDMA model ISO/IEC 144443A/B ISO/IEC 15693 DC Protocol Standard: EN61851-23/ DIN70121,ISO 15118 OCPP 1.6	-	Mode 4	-	-
16	Verde mobility	AC dual gun	AC charger Type 2	-	3.3kW-7.4kW per output.	-	-	OCPP 1.6 over GSM/ WIFI/sigfox Dual output with a range Authentication using APP and RFID.	-	Mode 2	-	-

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
17	Uznaka Solutions pvt. Ltd	Single Gun AC Charger	AC Type 2 charger	230 Vac + 10% or -6%, 50Hz 415 Vac + 10% or -6%	7.4kW, 230 Vac, Max 32A 22kW, 415 Vac, Max 32A 10kW, Each Outlet 230 Vac, Max 15A	1. IEC 62196-2 Mode 3, Type 2 2.IEC 60309	1 1 3	1.Between Charger and Vehicle Type-2 As per IEC 61851-1 As per BEVC-AC0001 Specification 2.Between Charger and CMS OCPP v 1.6 or above - 10/100 Bast-T Ethernet (Standard) or Optical GSM Modem (2G/3G/4G) and Wireless (Optional	-	Mode 2 Mode 3	65,000/- for 4.5kW 80,000/- for 22kW	1. 2,3,4W 2.4W 3. 4W
		Bharat AC 001	AC charger	-	-	3output socket	-	OCPP 1.6 over GSM/WIFI ARAI complain	-	-	-	-
		Hybrid AC charger	TYPE 2 AC charger	-	-	3 output of range 2*3.3kW IEC 60309-1*	-	OCPP 1.6 over GSM/WIFI	-	-	-	-
		(AC Type-2 / AC002)	AC charger	-	3.3kW AC	-	-	OCPP. Pro S and Pro M devices can be connected for OCPP 1.5 and load management	-	-	80,000/-	4-Wheeler
		DC Wall box	DC charger	-	24 kW 60 A high output current	Single or dual outlet: CCS and CHAdeMO	-	OCPP	-	Mod e4	8Lakhs/-	4-Wheeler
		TRONX DC Tower – 15 KW	DC charger	-	15 kW DC charging 200 A high output current	Single outlet: GB/T	-	OCPP 1.6/2.0 Capability for remote services	-	Mod e4	-	4-Wheeler
		TRONX DC Tower – 50 KW	DC charger	50 kW DC charging 125AMax. output current	Two outlets supporting CCS2 combo and CHAdeMO and an optional AC type-2 connector.	-	-	OCPP 1.6/2.0 Capability for remote services	-	Mod e4	-	Electric cars, pick-up trucks and minibuses
		TRONX-AC001	AC charger	I/P 11kW	O/P 10kW	-	-	-	-	Mod e1	70,000/-	Plug-in hybrid electric vehicles
18	Tirex	60kW EVFC CCS CHAdeMO EV Charger	CCS, CHAdeMO, AC Type 2	-	DC power up to 60 kW, AC power up to 43 kVA	-	-	-	-	Mod e4	-	4-Wheeler
		DC charging Wall-mounted	DC	415 V	20KW O/P Voltage 40V – 100V Variable	-	-	Communication Interface CAN	Automatic Charging or Manual Charging Optional	Mod e4	-	Electric cars, taxis, engineering vehicles and coaches.
		AC Charging EV Mini	AC	3 Phase, 5 Wire AC System (3Ph, N, E), 50Hz Nominal I/P voltage: 3 Phase, 415V	230 Vac, Single Phase, 15A each as per IS 12360	3 Independent Charging Sockets as per IEC 60309	3	Between EVSE and Server OCPP 1.6 and higher Between EVSE and CMS Ethernet (Standard), 3G and 4G	-	Mod e1	-	Cars, taxis, truck, bus and other slow charging.

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
19	Amplify Mobility (Amplify cleantech solution private limited)	AC V-Charge	AC	208 -240 VAC, Single Phase, 30 A (Max)/415 VAC Three Phase	208 -240 VAC, Single / Three Phase, 30 A (Max), 50Hz, 3.3 KW to 22KW	IEC 60309 / IEC 62196(Type 2)	5	EVSE to VehicleJ1772 communication / Type 2Cloud Connectivity2G / Wi-Fi(optional) Other Bluetooth(optional) OCPP 1.6/ 2.0	-	Mode 2	90,000/-	4-Wheeler
		BHARAT AC 001	AC charger	-	208-240 V AC,3.3kW	-	3Pin	-	-	Mod e1	42,500/-	2,3 and 4Wheeler
		POD (Smart and Simple home and commercial Charging)	AC charger	208 -240 VAC, Single Phase, 15 A (Max)	3.3 KW max	-	16A, 3Pin socket	2G/Wi-Fi Bluetooth optional	-	Mode 1	15000/-	4-Wheeler
		DC for 2,3 wheelers	DC charger	-	0.75 to 2 KW	Multiple Connectors	-	-	-	-	-	2,3 wheelers
		Bharat DC-01	DC charger	-	10 to 15 KW	Compatible with GB/T	-	OCPP 1.6	-	Mod e4	-	4-Wheeler
		DC Wall box (Wall mountable DC charging station)	DC charger	-	Up to 25 KW	CCS / CHAdeMO dual	-	RFID reader Cloud connectivity OCPP 1.6	-	Mod e4	-	4-Wheeler
		DC -Quick(Rapid DC charging stations for 4-wheelers)	DC fast charger	-	60 to 120 KW	GB/T Compliant	-	RFID Reader Cloud Connectivity IP54 protection	-	Mod e4	-	4- Wheeler
		DC Ultrafast (Super-fast charging for 4-wheelers and buses))	DC ultrafast charger	-	150 KW	-	Up to 3 Connectors	Configurable Grid Overload Protection	-	Mod e4	-	4- Wheeler and buses

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
20	Okaya Power (These chargers are able to charge all Electric Vehicles of IEC 60309 (Bharat Ac001), IEC 62196 - 2 (Type 2 AC), CCS - 2, CHAdeMO & GB/T charging standards compliance in AC Charger 230V or 415V and in DC Charger output voltage up to 750/1000 V)	AC Wallbox Charger	-	230VAC, 50Hz 415 Vac+10% or -6%,50 Hz 415 Vac+10% or -6%,50 Hz	7kW,230VAC max 32 Amp 22kW 10kW	IEC 62196, Type 2 IEC 60309	1 1 3	Charger and Vehicle Type-2 Asper IEC61851-As per BEVC-AC0001Specification Charger and CMS:- OCPP v 1.6 or above - 10/100 Base-T Ethernet (Standard) or Optical GSM Modem (2G/3G/4G) and Wireless(Optional	-	Mode 2	75,000/	2,3,4-Wheeler
		AC Wallbox Charger	AC Charger	415VAC, 50Hz	21 kW,415VAC max 32 Amp	IEC 62196-2, Mode 3 Type 2	1	IEC 62196, IEC 61851 OCPP v 1.6 or above GSM and wireless option	-	Mod e2	100000/-	-
		Bharat AC EV Charger	AC charger	415VAC, 50Hz	Each outlet 230 VAC max 32 Amp, 10kW	with 3 3.3kW IEC 60309 socket	3	As per BEVC-AC001 Specification OCPPv 1.6 or above GSM and wireless option	-	Mod e2	55000/-	4-Wheeler (Car)
		Bharat DC EV Charger	DC charger	415VAC, 50Hz	1)15 kW40-100Vdc max 200Amp 2)20kW40-100Vdc max 100Amp 3) 30kW, 40-100Vdc max 200Amp	GB/T 20234.3	1) 1 2) 2 3) 2	Between EV Charger and EV CAN-based communication as per AIS-138 OCPP v 1.6 or above GSM and wireless option	-	Mod e 4	1.230000 for 15kW 2.10000 for 20kW 3..410000 for 30kW	-
		DC Wallbox Charger	DC charger	415VAC, 50Hz	20kW, 200-1000Vdc	CCS-2/ CHadeMO	1	Between EV Charger and EV IEC 62196, IEC 61851 for CCS-2 AND JEVS G105 for CHadeMO OCPP v 1.6 or above GSM and wireless option	-	Mod e4	750000/- for CHadMO 700000/- for CCS2	4-Wheeler (Car)
		Single Gun Quick DC Charger	DC fast charger	415VAC, 50Hz	1)40kW, 200-1000Vdc 2)60kW, 200-1000Vdc 3) 80 kW, 200-1000Vdc	CCS-2/ CHadeMO	1) 1 2) 1 3) 1	Between EV Charger and EV IEC 62196, IEC 61851 for CCS-2 AND JEVS G105 for CHadeMO OCPP v 1.6 or above GSM and wireless option	-	Mode 4	1.1100000 for 40kW, CHedeMO 1000000 for 40kW, CCS2 2. 1150000 for 60kW 3. 1350000 for 80kW	4-Wheeler (Car), Buses

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
		Dual Gun Fast DC Charger	DC Charger	415VAC, 50Hz	120kW, 200-1000Vdc	CCS-2/ CHadeMO	1	Between EV Charger and EV IEC 62196, IEC 61851 for CCS-2 AND JEVS G105 for CHadeMO OCPP v 1.6 or above GSM and wireless option	-	Mode 4	-	4-Wheeler (Car), Buses
		Combo 3 in 1 EV Charger	Combo Type	415VAC, 50Hz	1. DC O/P 1 60kW 200-750 Vdc 2. DC O/P 2 60kW 200-550Vdc 3. AC O/P3 22kW AC 3Phase	1.CCS 2 2. CHadeMO 3. Type 2 4.IEC 62196	3	Between EV Charger and EV, (PLC) CCS-2, (CAN) CHadeMO and Type 2 as per IEC 61851 (1) OCPP v 1.6 or above GSM and wireless option	-	Mode 3 Mode 4	1150000/- for CCS2	4-Wheeler (Car), Buses
		Combo 3 in 1 EV Charger	Combo Type	415VAC, 50Hz	1. DC O/P 2 60kW 200-1000Vdc 2. AC O/P3 22kW AC 3Phase	1.CCS 2 2. CHadeMO 3. Type 2 4.IEC 62196	3	Between EV Charger and EV, (PLC) CCS-2, (CAN) CHadeMO and Type 2 as per IEC 61851 (1) OCPP v 1.6 or above GSM and wireless option	-	Mode 3 Mode 3 Mode 4	1200000/- for CCS2	4-Wheeler (Car), Buses
		Portable EV Charger	AC Charger	230Vac, 50Hz	230Vac, 16Amp	Type 2 IEC 62196	1	Between EV and charger IEC 62196, IEC 61851	-	Mode 1	-	Compatible with type 2 vehicle
21	(Voltaic) TVESAS Electric	BHARAT AC-001	AC Charger	3Phase, 415VAC (374~440VAC), 50Hz	3.3KW 15Aper OutputSocket	IEC60309 (Three Nos. of Socket)	3	RFID or QR Code or OTP-based charging Authentication Charger & CMSO CPP1.6J Network Internet (2G/3G/4G), GSM, Ethernet	94%	Mode 1	44,000/-	2, 3, 4-wheeler
		BHARAT DC-001	DC	-	-	-	-	-	-	Mode 4	-	-
		Type 2	AC Charger	1 Phase, 230 VAC (195~245VAC), 50Hz 3 Phase, 415 VAC (395~440VAC), 50Hz	7.4 KW 230 VAC, 32A 22 KW415VAC, 32 A	EC62196-2 IEC62196-2	1 1	EV & Charger CAN Communication Charger & CMSOCPP 1.6JNetworkInternet (2G/3G/4G), GSM, Ethernet, Wi-Fi (Optional)	94%	Mode 3	59000/-	4-Wheeler
		DC Wallbox	DC	3 Phase, 415 VAC (374~440VAC), 50Hz	25 KW IEC CCS Combo 2, 200-500 Vdc, 60A max, 25KW max. (Optional: SAE DC) Output 2 Rating CHAdeMO, 50-500 Vdc, 60 A max, 25 KW max, DIN 70121	CCS2 & CHAdeMO (CE & IEC Compliance)	-	EV & Charger CAN Communication Charger & CMSOCPP 1.6JNetworkInternet (2G/3G), GSM, Ethernet	92%/ Compliant with IEC 61000 -3-12	Mode 4	5.90 Lakh/ Piece	4-Wheeler

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
22	RRT Electro Power	DC Fast charger 10kW	DC Charger	Input: 415V AC, -10%/+15%, 50Hz + 5%, 3 Phase	Output Voltage: 40 to 100VDC Output power: 10kW Output current: 135A max	GB/T 20234.3:2015	1	CAN 2.0B OCPP	-	Mode 4	-	-
		DC fast charger 15kW	DC Charger	Input: 415V AC, -10%/+15%, 50Hz + 5%, 3 Phase,	Output Voltage: 40 to 100VDC Output power: 15kW Output current: 200A max	GB/T 20234.3:2015	1	CAN 2.0B	-	Mode 4	-	-
		DC fast charger 15kW	DC Charger	Input: 415V AC, -10%/+15%, 50Hz + 5%, 3 Phase	Voltage: 40 to 100VDC 40 to 100VDC Power: 10kW Current: 135A Max.	GB/T 20234.3:2015 GB/T 20234.3:2015	2	CAN 2.0B OCPP	-	Mode 4	-	-
		Type2 EVSE	AC Charger	Input: 85V to 265V AC, Single Phase, AC	-	-	-	-	-	-	-	-
23	EVTeq	100k Wcharger	DC Charger	Line voltage 380V 3phase 45-55 Hz	Nominal voltage: 450/700V O/P Current 0-200A O/P Power 100kW O/P voltage range 350-750V	CCS Combo 2+CHadeMO	-	BMS Communication CAN [2.0] CHadeMO, PLC Combo,	-	Mode 4	-	E-Car
		20kW wall-mounted charger	DC Charger	line voltage 380V 3phase 45-55 Hz	Nominal voltage: 450/750V Current 0-40A O/P Power 20kW O/P voltage range	CCS Combo 2+CHadeMO	-	BMS Communication CAN [2.0], GB/T, CHadeMO	-	Mode 4	-	E-Car
		50kWcharger	DC Charger	Line voltage 380V 3phase 45-55 Hz	Nominal voltage: 450/700V O/P Current 100A O/P Power 50kW O/P voltage range 350-750V	CCS Combo 2+CHadeMO	-	BMS Communication CAN [2.0] CHadeMO, PLC Combo,	-	Mode 4	-	E-Car
		200kW	DC Charger	Line voltage 380V 3phase 45-55 Hz	Nominal voltage: 700V O/P Current 200A O/P Power 200kW O/P voltage range 350-750V	CCS Combo 2+CHadeMO	-	BMS Communication CAN [2.0] CHadeMO, PLC Combo,	-	Mode 4	-	E-Car and Bus
		Ground-mounted dual22 kW charger	Dual type	230 V for AC single phase OR 380V for 3-phase 45-55 Hz	7kW, 22kW	IEC 62196-2	2	OCPP Complaint optional	-	Mode 2	-	Suitable for all-electric vehicles
			DC Charger	-	15kW	-	1	-	-	Mode 4	-	-

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
24	P2 power	Bharat AC001	AC Charger	415V (+6% and -10%) as per IS 12360, 50Hz, ±1.5Hz	Nominal Output Voltage 230Vac	IEC 60309	3	Protocol (EVSE & Central Server) OCPP 163 Between EVSE and CMS Ethernet (Standard), 4G Fall Back 3G (Optional)	-	Mode 1	-	2,3 and 4-Wheeler
		Bharat DC001	-DC Charger	3Ø, 415V (+6% and -10%) as per IS 12360 50Hz, ±1.5Hz	48V/60V/72VDC	Output connector with GB/T 20234.3 Compliance	-	User Authentication ISO/IEC 14443 A RFID for user authentication B/w EVSE and Vehicle CAN-based communication as per AIS138-2 B/w charger and Central Server OCPP v1.6 – 10/100 Base-T Ethernet (Standard) / Optional GSM Modem (4G Fallback 3G)	-	Mode 4	-	2,3 and 4-Wheeler
26	Trinity clean Tech	-	-	-	-	-	-	-	-	-	-	-
27	Cellerite System Pvt Ltd	-	-	-	-	-	-	-	-	-	30,000/	-
28	Battre	Battre RE Charger	On/Off Switching Plug unit with power consumption measurement	220V/ 50Hz AC 16A	3.3kW	3-Pin India/ Europe Compatible	3-Pin Power Socket with Neutral Live and Ground	Bluetooth 4.0, 2.4Ghz, Wi-Fi	-	-	3000/-	2-Wheeler
29	Tucker Motor	Bharat EV DC 001 - IP54	-	-	200A	-	2 Pin	-	-	Mod e4	2.50 Lakh/ Piece	2,3 and 4-Wheeler
30	Kirana Charzer	-	-	-	-	-	-	-	-	-	10,000/-	2,3,4 Wheeler

Sr. No	Charger Manufacturer	Charger Name	Charger Type	Input Rating	Output Rating	Connector Types	No. of charging gun	Communication	Efficiency	Charging Type		
31	EVFast	EVFAST LiteAC Charger	EC-62196-2	AC 230 V (±)15%	3.5 kW Max	Type 2, AC Single Phase,	-	Between EV Charger and EVType-2 AC as Per IEC 61851-1 User Authentication RFID	-	-	29,500/ Unit	2,4-Wheeler
32	Shreeji Enterprise	AC Charger	AC charger	230v,	3.3KW-7.4KW, 3-phase Up to 22KW1-phase	Type 2 cable and plug Type 2 socket with shutter	-	OCPP 1.6J GSM, Ethernet, Wi-Fi Authentication via RFID and APP	-	-	36,000/ Piece	-
33	Axonify	Atom AC Wallbox AXBOX001	AC Charger	230V 1-Ph AC, 415V 3-Ph AC	3.3 kW, 7.2 kW… 22 kW	Type2 AC (IEC 62196)	-	3G, 4G, Ethernet OCPP 1.6, 2.0*	-	Mod e2	45,000/-	2,3,4 Wheeler
		Atom Public AC Charger	AC Charger	230V 1-Ph AC, 415V 3-Ph AC	3.3 kW, 7.2 kW… 22 kW	Bharat AC001, J1772, Type2 AC,	-	OCPP 1.6, 2.0*3G, 4G, Ethernet	-	Mod e2	-	2,3,4 Wheeler
		Fast Charger	DC Charger	380-480 V ac 3 o (50-60Hz)	15 kW, 30 kW… 150 kW	Bharath CHAdeMO, CCS-1 / 2, GB/T	-	OCPP 1.6, 2.0* 3G, 4G, Ethernet	-	Mod e4	-	all types of electric vehicles
34	Suncov Energy Private Limited"	Combined Charging System	Electric Car Charger	-	15-200kW, 25-63 A	AC-DC Type 2	2	-	-	Mod e3 Mod e4	3.25 Lakh/ Unit	4-Wheeler
35	MassTech	DC Fast Charger	DC Charger	Three Phase 380-440V	10-200kW	(GB/T, CCS, CHAdeMO)		-	≥95% (Load:50~100%)	Mode 4	3,98000 - 5,00000.00	Bus and 4Wheeler
		AC Charger	AC Type 2	Single phase 230V, 32 A	2kW ,32 A to 43 kW	Type 2	1	-	-	Mode 2	70,000/- for 2-10kW	2,3,4 Wheeler

IS 17017 part 1 is an Indian standard issued by the Bureau of Indian Standards in July 2018 (BIS, 2018). It provides the general requirement of EV supply equipment.

3.10.2 EV CHARGING STANDARDS IN INDIA

IS 17017 part 1 is an Indian standard issued by the Bureau of Indian Standards in July 2018 (BIS, 2018). It provides the general requirement of EV supply equipment. It is applied to the charging station or EV supply equipment used to charge EV with rated input and output supply voltage of 1000 V AC and 1500 V DC. This standard covers the following aspects:

- Operating modes and characteristics of charging station
- Connection specification between EV and charging station
- Electrical safety requirements of charging station

The standard mentions all the definitions related to the EV charging system. The standard defines the charging station/EVSE of charging, types of charging cases based on the attachment status of charging cable, insulation, and its types. The functionality of various pins, conductors, and cables are briefed in the standard as well. The classification of charging stations based on input and output power supply, environmental condition, accessibility, mounting methods, and charging modes has been done. A charging station is also classified based on protection against electric shock.

Further discussion on charging modes and functions is provided below.

Mode 1

The EV is connected to a standard AC socket via a connector and cable assembly with a controlling contact pilot pin absent in the mode. A protective conductor should be connected between the plug and the vehicle connector. The current and voltage rating of Mode-1 in the single-phase and the three-phase condition is given in Table 7. Due to the absence of a control pilot pin, Mode-1 does not perform smart charging.

Table 8: Current and voltage ratings of Mode 1

	Single-phase	Three-Phase
Maximum voltage rating	240 V	415 V
Maximum current rating	16 A	16 A

Mode 2

In this mode, the EV is connected to the supply socket with cable and charger assembly constituting of control pilot pin that facilitates smart charging. Electric shock protection using a protective conductor is also enabled in this mode of charging. Mode-2 chargers are designed to be wall-mounted or to be placed in a shock-resistant enclosure. The current and voltage rating of Mode-2 charging is given in Table 8.

Table 9: Current and voltage ratings of Mode 2

	Single-phase	Three-Phase
Maximum voltage rating	240 V	415 V
Maximum current rating	32 A	32 A

Mode 3

In this charging mode, the EV is connected to AC supply equipment and is permanently connected to the supply network. The control pilot pin is present in Mode-3 charging, supporting smart charging via power modulation as per the system requirement.

Mode 4

In Mode-4, EV is connected to AC or DC supply network via DC charging station with control pilot pin. The charging station for Mode-4 charging should provide protective earthing to the vehicle connector.

There are some mandatory functionalities of Mode 2, 3, and 4 related to charging station operation.

- Continuous protective conductor checking
- Verification of proper connection between EV and EVSE
- Energization and de-energization of power supply
- Maintaining current within maximum limits

Any charging equipment with more than one charging gun should simultaneously and strictly perform the above functionality irrespective of other gun's operation. While performing charging operations, continuity checking of protective conductors needs to be done.

In Mode-2, protection earthing between the in-cable control box and EV is checked regularly via the in-cable control box. In Mode-3 and Mode-4 charging, the charging station monitors the protective earthing connection between EV and charging station. In case of loss of continuity of protective earthing, i.e., opening a control pilot circuit for 100ms or incapability of verifying protective earthing for 3s, the supply to the EV should stop automatically.

IS 17017 part 1 standard also provides communication information between charging stations, EV, and management systems. Standard IS 17017 provides the necessary information on protection from electric shocks and other adverse conditions with the respective safety requirements and standards. Protection against electric shock covers protection against electric shock, fault protection, protective conductor, and residual current protection. In addition to this, safety requirement from signalling circuits, and isolation transformer is given.

Cable assembly requirements, conductive electric interface requirements, and charging station constructional requirements are also presented in detail. The conductive electric interface covers the requirements and rating of various connectors with the name of the respective standards. Cable requirement covers the electrical rating and dielectric withstand capacity of the cable, construction requirement, and cable management.

The dielectric withstand capability of the AC charging station is further divided into withstand voltage and impulse dielectric withstand voltage. AC withstand voltage should be applied for 1 min for 50Hz power frequency. In class I EVSE, (phase voltage+1200 V) RMS voltage should be used in common mode (circuit in relation with conductive part) and differential mode (electrically independent circuit and other conductive parts) as mentioned in 5.3.3.2 of IS 15382 part 1:2014. In class II EVSE, twice of (phase voltage +1200 V) RMS should be applied in common and differential mode as given in 5.3.3.2.3 of IS 15382 part 1: 2014. The impulse test for impulse dielectric withstands circuit is also given in IS 15382 part 1:2014.

Various tests like damp heat functional tests, operating temperature limit tests and mechanical strength tests with their respective standards are provided in IS 17017. Overloading protection of cable assembly should provide using a circuit breaker fuse or a combination of both. If the protection is designed with devices other than these, it has to trip within 1 min of current exceeding 1.3 times the rated current. In the case of short circuit protection, value should not exceed 75000 A2s and 80000 A2s for Mode-3 and Mode-3 (case C).

The standard mentions the necessary marking and instruction requirements of the charging station. The installation manual should completely mention the characteristics of the charging station. The user's manual for an installed charging station should be provided to the user. It should include information related to adaptors, conversion adapters, and cord extension sets. The manufacturer should also provide durable marking on the equipment covering complete information, rating, manufacturing, dates and necessary information like protection type and insulation type. Durability test of this marking by rubbing the marks with a cloth soaked in water and petroleum sprit (separately) by hand for 15s is provided to check the charging station marks supplied by the manufacturer.

Detailed information about the general requirement, specifications and tests for AC and DC charging stations is provided in AIS-138 Part 1 and AIS-138 Part 2, respectively. Bharat AC001 and Bharat DC001 are two standard charging stations provided for the Indian charging scenario (DHI, 2017). Bharat AC 001 support AC charging with maximum current and power rating of 15 A and 3.3 kW.

Bharat AC001 and Bharat DC001 are two standard charging stations provided for the Indian charging scenario (DHI, 2017). Bharat AC 001 support AC charging with maximum current and power rating of 15 A and 3.3 kW.

The IEC 60309 connector has N: neutral, L: line, and G: ground pins. This standard allows charging three vehicles simultaneously from a three-phase AC supply. This is low power charging. Hence a specific communication standard between EV and EVSE is not specified in the standard. In contrast, communication between the EVSE and the central management system is defined as OCPP 1.5 and higher versions.

Bharat DC standard charger DC001 is defined for a maximum rating of 200A and 15kW (DHI, 2017). The output voltage can be 48V/60V/72V as per battery configuration. Communication between EV and EVSE is done using GB/T protocol over CAN bus communication. OCPP 1.5 and higher versions are adapted for communication between EVSE and the central management system.

Smart charging solution tools available in India include charging network providers and central management system providers. Table 9 mentions some of the smart charging solution providers in India.

Table 10: Smart charging solutions available in India

Sr. No	Type of smart charging product	Organisation	Explanation
1	Charging network provider	Fortum India	Provide charging solution on charge and drive platform
2	Charging network provider	TATA Power	Offers charging network for all types of location sites
3	Charging network provider	Okaya power	Provide operation and management system and monitoring system for transport and fleets
4	Management system provider	BrightBlu	Provide charging management software
5	Central management system provider	Numocity	Provide CMS and IoT based solutions
6	Charging solution and network provider	Volttic	Provide Ac-001 Dc-001 type of chargers and solutions using a mobile app
7	Charging network provider	Chrage+Zone	Provide customized charging solution
8	Charging network provider	PlugNgo	Provide charging network installation service and charging management solution
9	Charging network provider	Tirex	Provide IoT based cloud CMS and mobile app for home, public, and fleet control

3.11 Smart EV Charging Projects

Several smart charging projects have been conducted and demonstrated in different EV rich countries considering the promising benefits and capabilities of smart EV charging. Details on a list of such smart charging projects including the completed and ongoing projects, are described below.

3.11.1 ELECTRIC NATION SMART CHARGING PROJECT

- **Time Duration:** 2016-2019
- **Location:** United Kingdom
- **Partners/ participants:**
  - Electricity distribution network operator: Western Power Distribution (Midland, South West, Wales)
  - Technical expert and analysis and trial manager: EA technology
  - Participant liaison and smart charge point installation and maintenance coordinator: Drive Electric
  - Developing an EV load detection algorithm: Lucy Electric
  - Project management: TRL (UK's Transport Research Laboratory)
  - Demand management system provider: Crowd Charge
  - Demand management system provider: Green Flux
  - 673 EV owners with domestic charging
- **Aim:** The project aims to demonstrate the effect of EV integration into a low-voltage distribution grid and investigate the feasibility of smart charging to mitigate the adverse effect of EV integration on the grid ("Powered-Up-Electric-Nation-Brochure.pdf," n.d.).
- **Methodology:** The project implemented a time-of-use tariff structure to encourage EV owners to smartly charge their vehicles, keeping in mind grid capacity limitations. GreenFlux smart charging solution utilizes the time-of-use structure to incentivize EV users. Forty-five different vehicles participated in trials from 18 different manufacturers. The most common manufactures are BMW, Tesla, Mitsubishi, Nisan, and Mercedes-Benz. These vehicles belong to three categories of EVs: Battery Electric Vehicle (BEV), Plug-in Electric Vehicle (PEV), and Range Extended Electric Vehicle (REEV) (it has an additional small generator to charge the battery). Participating percentage of different types of vehicles in this project is shown in Figure 45.

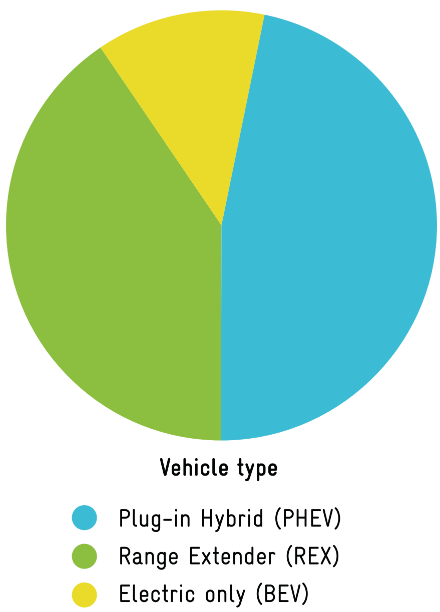


Figure 45: Approximate presence of different vehicle types in the project ("Powered-Up-Electric-Nation-Brochure.pdf," n.d.)

The project was divided into three phases to understand EV owners charging behaviour and its impact on the local grid.

Trial 1: Blind

This blind phase is when EV owners do not know about their vehicles' limited charging due to restricted available supply. During the high demand and low grid power capacity, the participating EV has been given limited charging without informing the participants. During such scarcity of power supply, maximum demanded power allocation is not possible. Because of this, the participants have to be managed without noticing the change in the charging rate.

Trial 2: Interactive

In the interactive trial, participants are provided with mobile applications from CrowdCharge and Greenflux to indicate following day energy requirements.

- Participants using Greenflux mobile application can access the data whether their vehicle is being managed or not. They can also make their charging session a higher priority to opt-out from being managed by the charging session.
- The smart charging from the Greenflux application shows that the option of higher priority is availed in only 2-3% of charging events which shows that this feature is not being exploited by participants and used only in necessary circumstances.
- Participants using mobile applications from CrowdCharge has the provision of current SOC level and desired SOC level for next travel. It ensures a sufficient SOC level for the next trip.

Trial 3: Incentives

In the third trial, the second trial options are incentivized based on the energy usage of participants at different times of the day. In this trial, the second trial options are modified based on the time-of-use tariff structure to earn shopping vouchers. Again, both service providers have introduced different incentivization strategies, as given below.

- For participants using CrowdCharge, the app has the option that if the vehicle is needed for more travelling usage in a day, then charging will start with more costs; otherwise, it waits to start charging at an off-peak time with lower cost.
- The Greenflux app users get rewards based on time of use of energy and are provided with the options to charge regardless of price or action of shifting following low-price hours. They can choose smart charging and learn about their rewards in the app based on the options.

"GreenFLux uses the following options in the app:

- Optimize time (charge regardless of price),
- Minimize cost (charge in off-peak period only)
- Optimize time and cost (charging could begin during the shoulder period but would avoid the peak price charging)

Each participating group's results show that the evening peak is disappeared and shifted as a sudden peak in off-peak night hours. The app results for participating EV owners' charging behaviour at trial-1 and trial-3 (incentivized) are given in Figure 46, showing the shift of charging load from day-time to off-peak time.

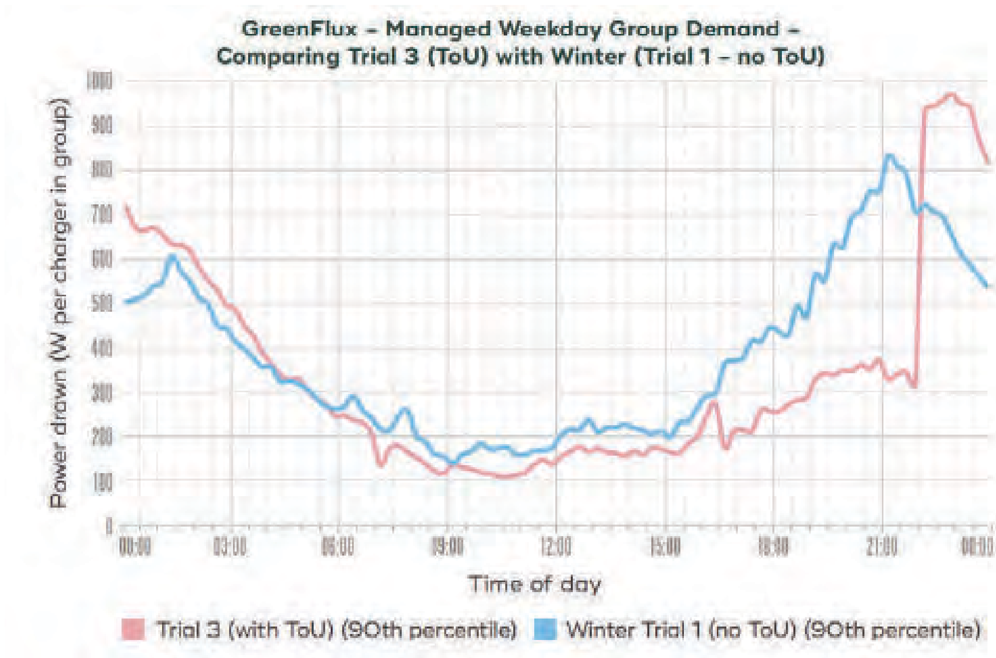


Figure 46: **Charging behaviour without and with incentivisation ("Powered-Up-Electric-Nation-Brochure.pdf," n.d.)**

Project analysis concludes that the well-defined EV tariff structure with smart charging provides a cost-effective charging schedule for EV owners. It improves owners' satisfaction and eliminates costly grid upgradation requirement.

- **Learning from Experience in the project:** The most important learning is that flexibility in charging load is a possibility. However, without incentive, it needs more management to shift the evening peak. Time-of-use incentives and mobile apps make smart charging easy for EV owners that increase satisfaction.

- **Conclusion:** Project analysis concludes that the well-defined EV tariff structure involved with smart charging provides a cost-effective charging schedule for EV owners. It improves owners' satisfaction and eliminates costly grid upgradation requirements.

3.11.2 ELECTRIC NATION VEHICLE TO GRID PROJECT

- **Duration of project:** Jan 2020 to Jun 2022(Ongoing)
- **Location:** United Kingdom
- **Partners/participants:**
  - Western Power Distribution (WPD) is the project Distribution Network Operator (DNO)
  - CrowdCharge is leading the project
  - DriveElectric is helping with the recruitment of trial participants
  - EA Technology is modelling the network impact
  - 100 EV owners
- **Aim:** Aim of the project is divided into objectives and are mentioned below ("Powered-Up-Electric-Nation-Brochure.pdf," n.d.):
  1. To study and explore the V2G smart charging impact on LV electricity network with actual end-users' data.
  2. To demonstrate V2G capability and manage the LV networks demand.
  3. To examine the sophisticated dynamic bi-directional energy services based on vehicle battery storage from various energy suppliers and their impact on the LV infrastructure.
  4. It also engages in recommendations of policy and commercial frameworks on V2G services.
- **Benefit to EV participants and participating industries:** The UK grid is focusing on low carbon technologies, and Electric Nation to Grid is one of the prime projects on the integration of EV in the grid. Increasing EVs have raised the power demand. This project manages the excess demand by charging the EV with smart charging in the local network.

The UK grid is focusing on low carbon technologies and Electric Nation to Grid is one of the prime projects on integration of EV in the grid

Project contributes the following benefits to the consumer

- Participants will receive a V2G charger worth approximately £5,500 or 7637 USD to use for the duration of the trial and can own the charger with a transfer fee of £250 or 347 USD
- Active participants can earn rewards of up to the monetary value of £120 or 167 USD.

Benefits to Industry:

- DNOs can better understand V2G by involving up to five different energy suppliers in the project.
- It helps energy suppliers understand V2G energy services and their impact on DNO.
- The project develops a collaborative and cohesive market for all participants by showing the practical benefits of smart charging.

The project is currently in the participant recruitment and hardware installation phase, so the actual trial methodology and data are not available.

Increasing EVs have raised the power demand. This project manages the excess demand by charging the EV with smart charging in the local network.

3.11.3 MILTON KEYNES COUNCIL: DOMESTIC ENERGY BALANCING EV CHARGING PROJECT

- **Duration of Project:** 2020 to 2022 (Ongoing)
- **Location:** Milton Keynes, Newport Pagnell, Olney
- **Partners/participants:**
    - Milton Keynes Council
    - Go Ultra Low Milton Keynes
    - Office for low emission vehicle
    - OLEV
    - CrowdCharge
    - 12 participants (V1G: 8, V2G: 4, stationary battery devices: 2)
- **Aim of the Project:** Through unidirectional smart charging (V1G) by controlling the charging power delivered, vehicle-to-grid charging (V2G), and home battery storage project tries to investigate the ways to balance the peaks of electricity use associated with charging electric vehicles at home ("Milton Keynes Council - Domestic Energy Balancing EV Charging Trial: V2G Hub | V2G Around the world," n.d.).

  The final aim is to use and manage these technologies to be available for EV owners to save money and reduce demand on electricity networks by balancing the load on the grid.
- **Methodology:** It will include pioneering technology for residential charging to perform intelligent bidirectional charging and discharging functionalities. This bidirectional charging will allow vehicle-to-grid and vehicle-to-home battery storage. The technology will exhibit V1G and V2G operations.

V1G:

- Only charges EV.
- It connects to the internet via home Wi-Fi.
- It has the advantage of cheap energy via dynamic pricing.

V2G:

- It includes the Bidirectional power flow, i.e., charging and discharging.
- It helps in balancing the local and global energy production and consumption considering the cost of electricity and greener energy.

Stationary Battery storage device:

- Larger internal or external wall mounted battery in the property.
- Preferable and beneficial to install alongside solar PV installations (to reduce early-evening peak).

3.11.4 MY ELECTRIC AVENUE CHARGING PROJECT

- **Duration of project:** Jan 2013 and Dec 2015
- **Location:** United Kingdom
- **Partners/Participants:**
  - EA technology
  - Nissan
  - Northern PowerGrid
  - Ricardo
  - Scottish and southern electricity networks
  - Fleetdrive electric
  - The University of Manchester
  - Automotive comms
  - Zero carbon futures
  - De Montfort university
  - 100 EV owners
- **Aim:** The project's aim is divided into two categories: commercial and technical (Cross and Hartshorn, 2016).
- **Technical aim:**
  - To understand the customer driving and EV charging habits and patterns.
  - To trial the equipment implemented to mitigate the impact of EV charging.
- **Commercial aim:** To do all procurement related to the project by non-DNO (distribution network operator) to evaluate the extent to which third party involvement accelerates deployment for the project.
- **Methodology:** ESPRIT is an intelligent control box (hardware that can control the charging process) that is used for performing smart charging. It works on temporary load curtailment and monitors and controls the EV load of clusters of participating groups. It is capable of controlling and managing EV load on the local network during the stressed conditions of the grid. It has demand-side management capabilities to protect the grid from overloads.
- **Learning from the project:**

It was noted that approximately 70% of users charge their vehicle once a day

Externally controlling the charging does not affect the service experience of the customer

Low carbon technologies need to be promoted.

- **Conclusion:** Results and analysis conclude that the Esprit technology is successful in load curtailment at necessary events. The results also concludes that it prevents system overloading and eliminates the requirement of network upgrades.

Results and analysis conclude that the Esprit technology is successful in load curtailment at necessary events. It also concludes that it prevents system overloading and eliminates the requirement of network upgrade.

3.11.5 THE PARKER PROJECT

- **Duration of the project:** August 2016 to July 2018.
- **Location:** Denmark
- **Partners/Participants:**
  - DTU
  - Nuvve
  - Nissan
  - Insero
  - Enel X
  - Groupe PSA
  - Mitsubishi Corporation,
  - Mitsubishi Motors Corporation
  - Frederiksberg Forsyning
  - 20EVs
- **Aim:** To demonstrate the EV's capability for grid support operations. The project is aimed to provide frequency support services from the vehicle-to-grid and enhance the grid facilities with EVs. The project investigates grid scalability and reliability ("Parker_Final-report_v1.1_2019.pdf," n.d.).
- **Methodology:** It performs frequency regulation services to the Danish grid. The configuration of the project network is shown in Figure 47.

  Frequency response services from a cluster of EVs are divided into two sites.
- **Test site:**
  - Denmark (Frederiksberg Forsyning V2G hub)
  - 10 Nissan e-NV200 EVs and 10 Enel V2G chargers controlled by a Nuvve aggregator

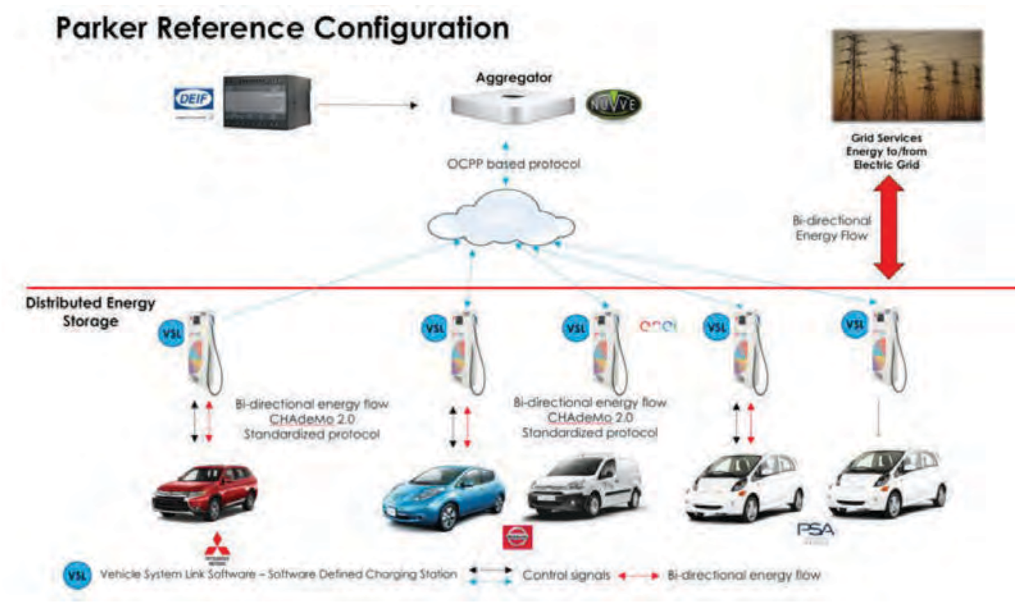


Figure 47: **System configuration in Parker project ("Parker_Final-report_v1.1_2019.pdf," n.d.)**

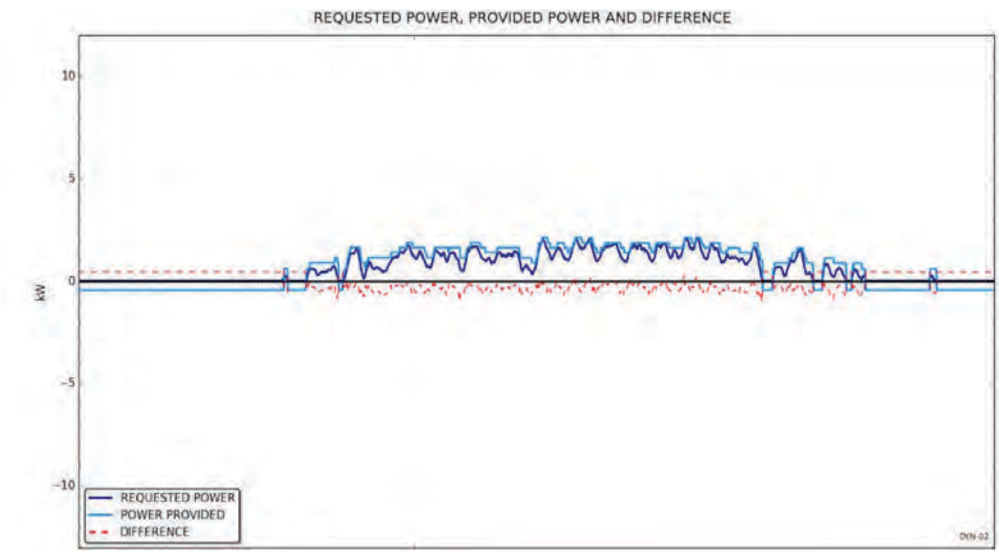


Figure 48: **Requested and demanded power for providing frequency support service ("Parker_Final-report_v1.1_2019.pdf," n.d. The project's result in Figure 48 shows that the supply of requested power using V2G service from participating.**

The project's result in Figure 48 shows the supply of requested power using V2G service from participating.

The vehicle-to-grid operation is coupled with DC V2G chargers, and it demonstrates the possible scaling in seven different directions, as shown in Figure 49.

Table 11: **Attributes for scaling the project in a different direction**

Number of Cars	Services	Duration
EV brand scaling	Battery size scaling	Scaling synchronous area
Information scaling		

Lack of EV owners' knowledge is also an important factor while providing V2G as a grid support service.

The project is scaled in different directions, as shown in Figure 49. to capture realistic conditions.

The project's experience: A lack of knowledge of EV owners is also an important factor to be considered while providing V2G as a grid support service.

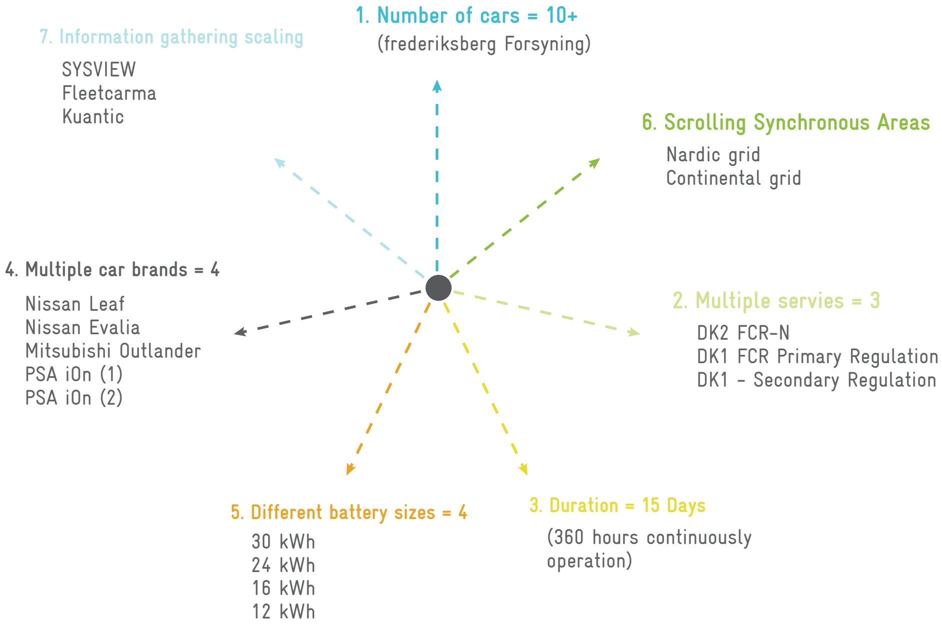


Figure 49: Scalability of the project in a different direction ("Parker_Final-report_v1.1_2019.pdf," n.d.)

- **Conclusion:** Results and analysis of the project conclude that V2G plays a significant role in grid support services. These services are in the form of active power support, reactive power support and integration of RE. Therefore, EV participants, DSO and TSO have revenue gain from V2G services. Battery degradation and lack of communication standardization are some of the technical challenges that need to be solved before implementing the framework on a large scale.

3.11.6 WINSMARTEV

- **Duration of project:** 1 October 2012 - 30 September 2016
- **Location:** University of California, Los Angeles
- **Partners/Participants:** University of California, Los Angeles (UCLA), Smart Grid Energy Research Centre (SMERC)
- **Aim:** This project aims to reduce energy costs and increase the stability of the local power system by managing the charging operations of EVs. It also demonstrates smart charging by remote monitoring and using WINSmartGRid ("UCLA Smart Grid Energy Research Center | SMERC," n.d.).
- **Methodology:** It is a demonstration and R&D project under the collaboration of UCLA and SMERC for remote monitoring and control of EV charging through a smart communications network called WINSmartGrid™. The scope of research was to focus upon distributed storage technology and Ancillary Services. However, in addition to the above service, stochastic modelling of user behaviour is important.

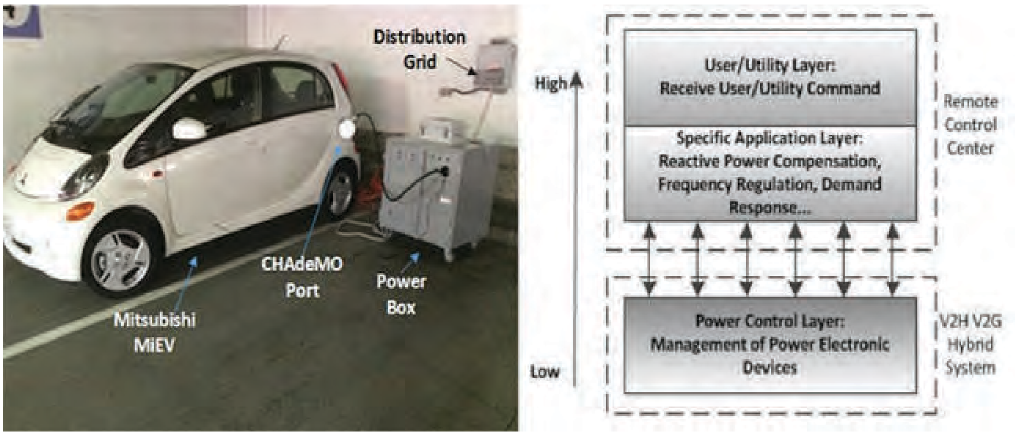


Figure 50: **Project demonstration system ("UCLA Smart Grid Energy Research Center | SMERC," n.d.)**

A customized V2G box is provided to Los Angeles Water and Pump department to perform a constant 1 kW V2G power flow into the grid, and the demonstration setup is shown in Figure 50.

- **Scope of research covers:**
  - Distributed storage: Distributed battery stores the energy and feeds it back to the grid at the required time.
  - Load sharing control: In V2G operation, controlling load-sharing as per the EV rating is vital to avoid over and under-utilization.
  - Ancillary services: The algorithm needs to be designed to provide ancillary service while keeping track of EV owners energy requirements.
- **Conclusion:** The project results and data provide various necessary directions for V2G services and load sharing to investigate and plan the large-scale roll-out of grid-integrated EVs in the region.

3.11.7 VEHICLE TO GRID DEMONSTRATION PROJECT

- **Duration of Project:** October 1, 2008 - December 31, 2010
- **Location:** University of Delaware Newark, Delaware, United States
- **Partners/Participants:**
  - University of Delaware Newark
  - AutoPort, Inc
  - AC Propulsion
  - 5 EVs
- **Aim:** The project aims to build, develop, and test vehicles with both Grid Integrated Vehicle (GIV) and V2G capabilities (Kempton et al., 2010).

The project aims to build, develop, and test vehicle with both Grid Integrated Vehicle (GIV) and V2G capabilities

- **Methodology:** Grid-integrated vehicles have built-in communication and control capabilities for simple and easy grid integrations. GIV is primarily designed as a transportation unit and has a low capacity of storage and charge-discharge capability. For building such a transportation specific and storage backup unit, the driving pattern is an essential factor. So, the project is focused on driving pattern analysis. A database of 500 vehicles with the one-second resolution is tracked for three years for driving pattern analysis.
- **Topics covered under the R&D project:**
  - Analysis of US driving patterns
  - Analysis of the market for EVs and V2G-capable EVs
  - Development and testing of GIV components (in-car and in-EVSE)
  - Interconnect law and policy
  - Development and filing of patents
- **Conclusion:** Built 5 EVs with a 35kWh Li-ion battery with a maximum speed of 90mph. It has grid-integrated charge-discharge capacity at the rate of 19.2kW at 240AC voltage.

3.11.8 BLUE BIRD SCHOOL BUS PROJECT

- **Duration of project:** 2017-2020
- **Location:** California, US
- **Partners/Participants:**
  - California Energy commission
  - Con Edison
  - NREL
  - US Department of Energy and all others
  - Six school buses
- **Aim:** The project's objective is to demonstrate the V2G capability of school buses ("Blue Bird Introduces All-New Electric School Bus Solutions," n.d.).

Built 5 EVs with a 35kWh Li-ion battery with a maximum speed of 90mph. It has grid-integrated charge-discharge capacity at the rate of 19.2kW at 240AC voltage.

- **Methodology:** School buses are chosen wisely because school buses have fixed root and operation time that gives the exact energy demand for the travel. Additionally, school busses have adequate non-operating time (night, weekend, holidays and summer). Also, the batteries of school buses are sufficiently large to provide V2G services. The fixed energy demand, a large amount of non-operating, and adequate battery size promotes using school buses for the demonstration project. The primary model indicated that each bus might earn between 5000$ to 25000$ per year for providing grid support and executing the demonstration project.

  The project is divided into two phases, viz, phase I and phase II.

Phase I:

In the first phase, six buses are retrofitted with the battery ratings as follows:

- 300 (Ah) lithium iron phosphate (LiFePO4) cells and each battery constitute 120 cells in the entire subsystem. So, the total capacity rating of the battery is 115 kilowatt-hours (kWh)
- For the V2G demonstration, two buses are provided with a bidirectional converter of 70kWh

Phase II:

Battery and inverter rating for demonstration in phase II is as follows:

- Up to a 155kWh battery (Lithium Nickel Manganese Cobalt Oxide battery);
- 150kWh bi-directional inverter

V2B/additional power delivery is also planned to be demonstrated in phase II.

- **Conclusion of the project:** The early stage of V2G is connected to several weaknesses and drawbacks, but there is a high potential for this technology (Lee et al., 2018). During summer, buses are not operational, so they can act as storage units and participate in V2G support that reduces the grid's stress due to the high usage of air conditioners.

3.11.9 CHARGE TO PROJECT

- **Project Duration:** 1 Nov 2014 – Jan 2016
- **Location:** Toronto, Canada
- **Participants/Partners:**
  - Ministry of Energy
  - Toronto Hydro
  - AddEnergies Technology
  - FleetCrama
  - AddEnergies
  - 30 EV owner
- **Aim:** The project aims to demonstrate the feasibility of a system with an EV smart charging strategy and capture the limitations, EV load curtailment availability, and the response of EV owners to real load curtailments and incentive structure (Bauman et al., 2016).

The project's objective is to demonstrate the V2G capability of school buses

Methodology: An EV local curtailment based smart charging is adopted to achieve the project objective. This smart curtailment considers three drivers' preferences and grid conditions. For performing EV smart charging, FleetCrama's connected car platform is used in the project. FleetCrama is a smart charging platform provider. It constitutes of four main components as follows:

FleetCrama data logger: It collects vehicle data by getting plugged into the vehicle's diagnostic port and collects the battery state-of-charge (SOC), location coordinates, and charging/ power.

FleetCrama's smart charging portal: It is a web portal where EV drivers provide driving preferences.

FleetCrama load management controller: It is a cloud-based controller that takes network information (maximum available power) and EV drivers' preferences. Based on the data, an optimal curtailment schedule is fixed to satisfy the requirements of both stakeholders.

- **Control pathway:** It is a pathway to curtail the EV charging load on the charging station by connecting to the controller. In this project, two pathways are used: 1: AddEnergies Core and Level 2 EVSE 2. Tesla API for Tesla chargers permits FleetCrama load management controller to control charging of Tesla chargers.

Actual working and signal flow for smart charging using FleetCrama is shown in Figure 51.

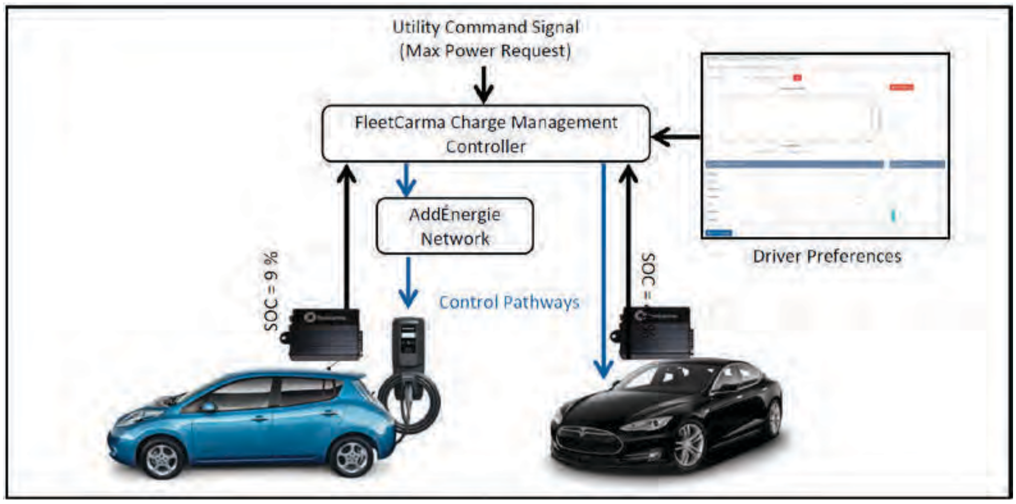


Figure 51: **Charge TO program smart charging provided by fleetCrama (Bauman et al., 2016)**

Drivers' preferences and grid data are taken using FleetCrama's web portal to perform smart charging. The web portal has two different views as driver's view and fleet charging view. Web portal view and functionalities are explained below and shown in Figure 52 and Figure 53.

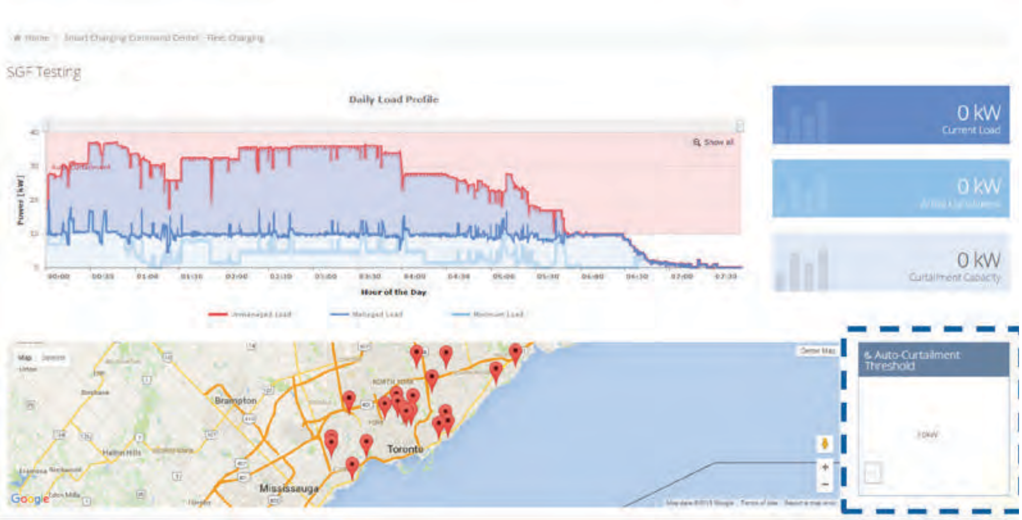


Figure 52: **FleetCrama's fleet charging view (Bauman et al., 2016)**

The driver's view driver has three options to manage his charging and curtailment: 1) 24-hr opt-out point, which indicates that the driver is not ready to participate in smart chart charging via load curtailment; 2) Time Charge Is Needed (TCIN), indicates the controller that the battery must have got fully charged ; 3) SOC opt-out setting, using which the driver indicates to the controller to not perform load curtailment below specified SOC level.

In fleet charging view, the utility provides maximum available grid power value, at which auto curtailment of EV charging will start. This information is provided under the auto-curtailment threshold option. In addition to this option, it has a day load profile plot that gives information on the previous day's load profile.

Figure 53: **EV owners view of FleetCrama smart charging display (Bauman et al., 2016)**

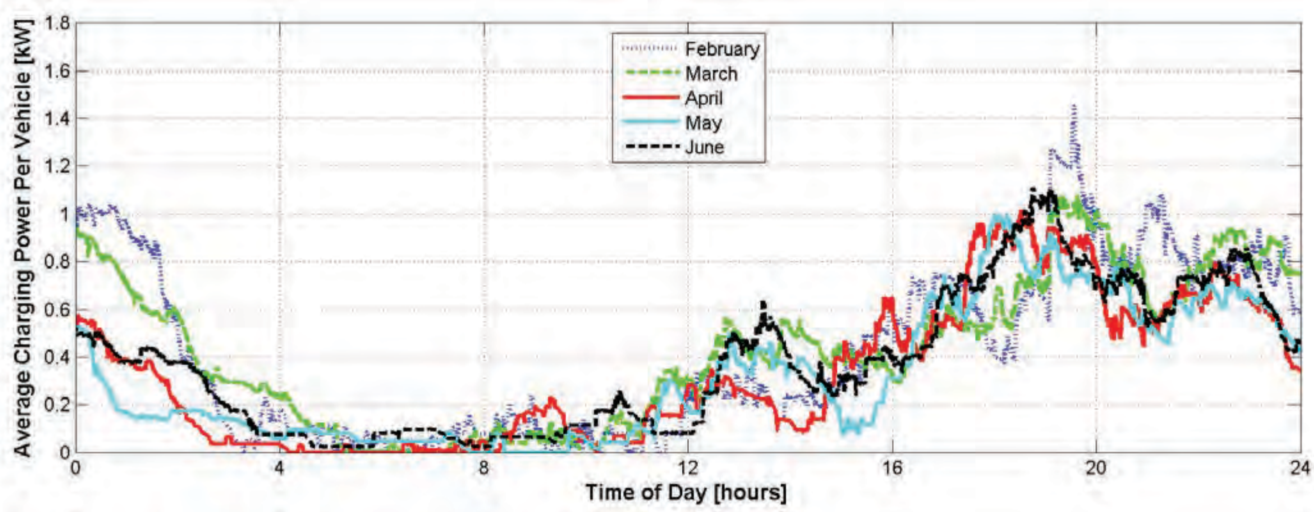


Figure 54: Charging without overnight charging schedule (weekdays) (Bauman et al., 2016)

The charging data of EV drivers are collected for weekdays and weekends to understand the need and requirement of smart charging in terms of load curtailment. Overnight charging is not a focus of this project, so the EV charging of participants without scheduled overnight charging is captured and shown in Figure 54 for weekdays.

It shows that the available EV charging load need to be ready for curtailment during the evening time on weekdays and weekends. Therefore, the instantaneous load curtailment analysis is performed using driver's preference data. This value shows that the capacity to shed EV charging load at the time of grid emergency and possible load shift reduces the local network's peak load.

InstanteousEV load cuirtaliment = Total load - (EV charging under TCIN option + EV charging under 24hr opt out option)

Figure 55 and Figure 56 shows the averaged instantaneous load curtailment capacity per vehicle for weekdays and weekend, respectively.

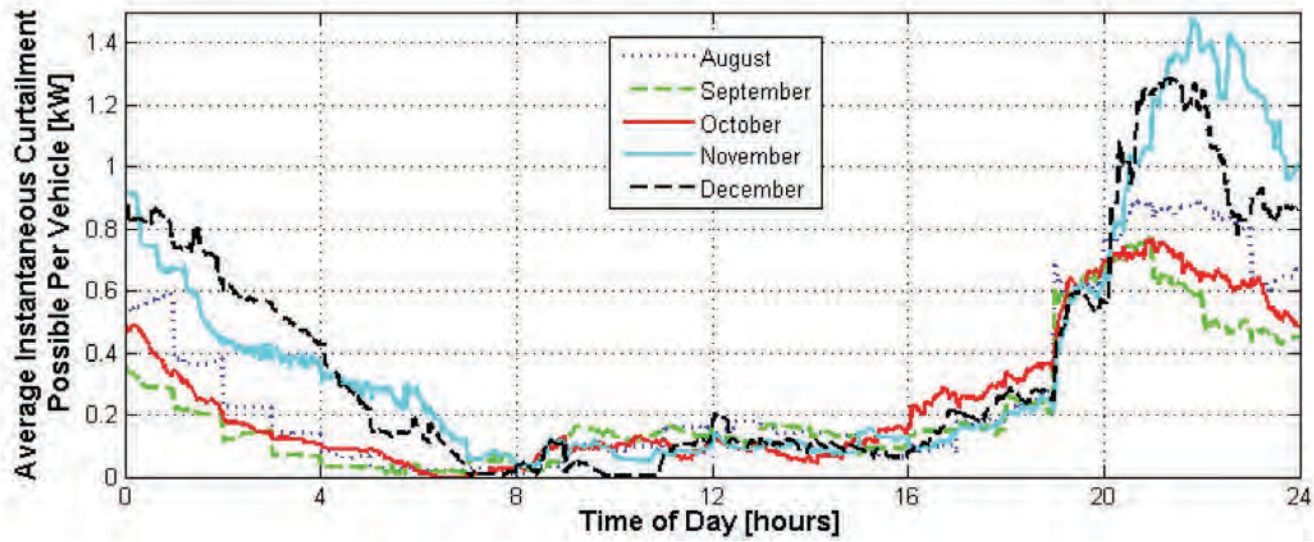


Figure 55: EV charging load curtailment possibility for weekdays (Bauman et al., 2016)

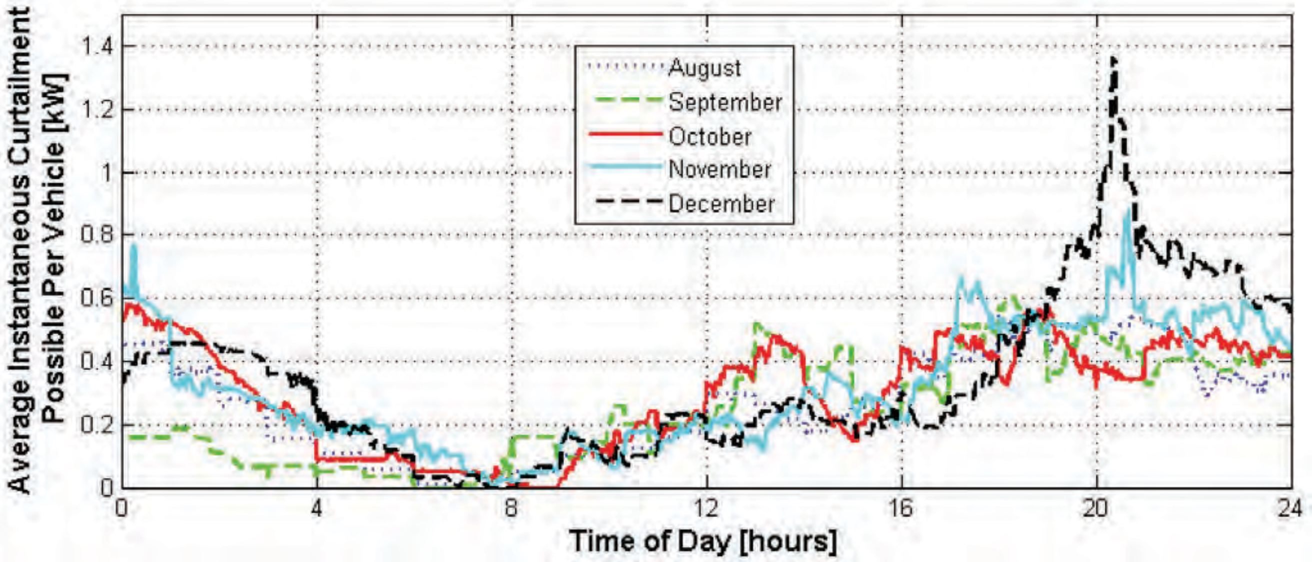


Figure 56: EV charging load curtailment possibility for weekends (Bauman et al., 2016)

- **The project has found two environmental benefits of smart charging:**
  – Improvement in renewable energy utilization
  – Reduction in grid emissions.

The shift in EV charging load to the RE reach hours reduces over the generation of RE. In other words, it reduces the duck-curve phenomenon, which requires a high ramp-up rate during the evening peak period. The second benefit of grid reduction is achieved by reducing the added generation requirement by charging curtailment and EV load shift operation.

Up to this phase in the project, no incentives are provided to users for participating in smart charging. In the next phase, an incentivization of the participants is performed. These incentives are divided into three groups: 1) Control group, which will receive a fixed amount (40 USD) regardless of their smart charging option, 2) Count-up group, which allows participants to earn the rewards (starting from 0 USD) for lowering SOC opt-out setting, 3) Count-down group, in which the driver will lose the rewards (rewards starting from a fixed value of 50 USD) for higher SOC opt-out option setting. Figure 57 shows the pre-incentive and post incentive participants for different SOC opt-out ranges. It depicts that most participants used to set SOC threshold at 40-50% range before incentives. But after incentivizing, the majority of drivers go with the SOC settings of 0-9%.

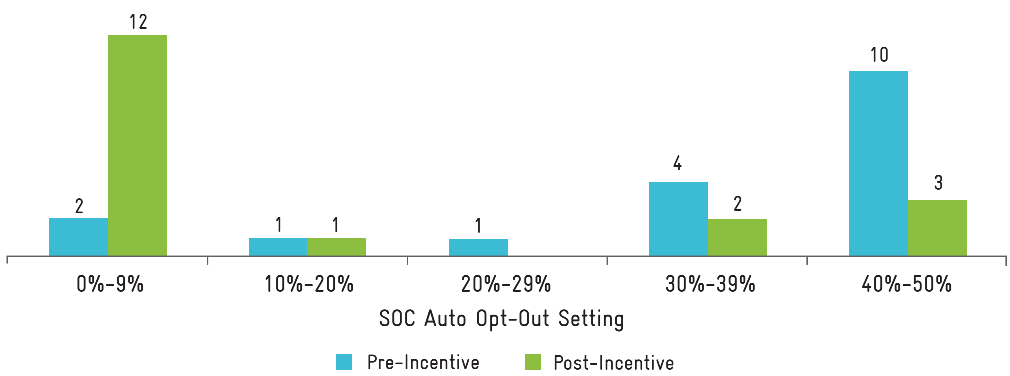
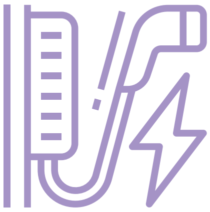


Figure 57: SOC Auto opt-out charging behaviour before and after incentives (Bauman et al., 2016)

The project concludes that 70-80% of charging load is shed at peak hours, but the algorithm ensures the battery will be fully charged for the next day's first travel.



- **Findings and conclusion of the project:** The project concludes that 70-80% of the charging load is shed at peak hours, but the algorithm ensures the battery will be fully charged for the next day's first travel. Results also show that simple load curtailment and load shift allows smart charging to maintain grid constraints and reduce costly grid upgradation requirements. Incentivized smart charging improves load curtailment and increases instantaneous load curtailment capability.
- **Experience from the project:** The project's main experience is that consideration of vehicle data before load curtailment is very important from the drivers' point of view. Another learning from the project is that 24% of the participants do not wish for any compensation other than their vehicle's data, and 44% wish for compensation below 20$/month. This shows that the value of threshold opt-out SOC and respective incentives are the main drivers in EV smart charging.

3.10.10 LEICESTER CITY HALL OPERATION PILOT

- **Duration of Project:** 2017-2020
- **Location:** Leicester, U.K.
- **Participants/partners:**
  - Hogeschool van Amsterdam: Jos Warmerdam
  - Cenex Nederland: Esther van Bergen
- **Aim:** To demonstrate technical requirements and benefits of Vehicle to Building V2B technology (Bentley et al.,).
- **Methodology:** V2B is not implemented and investigated in the project because of the unavailability of required infrastructure and arbitrage cost exceeding the profit. In contrast, V2G, in the form of frequency regulation, receives an extra payment for frequency service.

The project participants agreed to respond to changes in frequency from 50 Hz to 49.7Hz or 50.3Hz and export energy for up to 30 minutes

The project decided to work on firm frequency response (FFR) because of the low-entry capacity requirement. FFR is available in two variants Dynamic firm frequency response (DFFR) and static firm frequency response (SFFR). The project participants agreed to respond to changes in frequency from 50 Hz to 49.7 Hz or 50.3 Hz and export energy for 30 minutes. The second type of response, DFFR, occurs at normal operating conditions. Participants of DFFR need to respond in 2 seconds to restore frequency to the optimal value of 50Hz. Ideally, this response should last for 10 seconds, but it goes until a few minutes in some cases. DFFR participants will be paid for ramp-up that happens by increasing energy import/vehicle charging and ramp-down by decreasing energy export/vehicle discharging.

A virtual carport is proposed with PV and EVs in the system due to the lack of equipment for V2B or V2G operation. It was investigated how EV charging matches available energy from the solar PV system. Simulation studies on virtual carports are performed from 1st to 29th March 2019.

The other aspect of the project is the detection of the charging behaviour of EVs using charging data. Here, clustering and decision tree algorithm is used for charging behaviour detection.

Learning from Experience:

- Background knowledge gathering is significant in the early phases of site selection and equipment setup.
- Consider extra costs and losses corresponding to equipment while deciding demonstrating system.
- Consider a realistic future scenario while choosing additional devices and pieces of equipment. The council has considered only Nissan Leaf fleets of 30 kWh battery or more for establishing a bidirectional vehicle-to-grid charger in this project.
- Check all necessary certifications of equipment and devices to avoid additional time delays.
- The most important learning is to first perform a cost analysis before starting to work on real projects.

Conclusion: DFFR - Dynamic Firm Frequency Response is profitable to perform after preferably considering battery degradation cost also.

Though **National Electric Mobility Mission Plan (NEMMP) 2020** laid down the vision and roadmap for EV penetration in India, the scheme could not achieve the envisaged penetration targets.

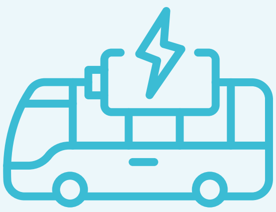
04

Gap Analysis of Indian States EV Policies from Smart Charging Perspective

AT CENTRAL LEVEL

Though National Electric Mobility Mission Plan (NEMMP) 2020 laid down the vision and roadmap for EV penetration in India, the scheme could not achieve the envisaged penetration targets. However, the various actions taken as per NEMMP guidelines has provided the kickstart for uptake of e-mobility and increased the awareness level among the consumers and industry players. There were several provisions enlisted under the policy, such as:

i. Permissive legislations: Legislations to permit usage of EVs in various areas.
ii. Operational regulations: Use of legislation framework and regulations focused on safety and emissions, vehicle performance standards, charging infrastructure standards, etc.
iii. Fiscal policy measures: Various trade-related guidelines for shaping the market, imports, and exports.
iv. Manufacturing policies: These are aimed at promoting EV investments. Specific policies are aimed at incentivizing EV manufacturing and early adoption through demand creation initiatives.
v. Schemes and pilot projects: To facilitate infrastructure developments.
vi. Research and development: Policies and guidelines to encourage R&D activities in the EV sector.



National Electric Mobility Mission Plan (NEMMP) 2020 laid down the vision and roadmap for EV penetration in India, the scheme could not achieve the envisaged penetration targets.

However, these provisions were not effectively implemented under the NEMMP scheme. After NEMMP, the Central Government launched the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) scheme in 2015 to enhance hybrid and EV technologies in India. The overall scheme (divided into two phases, I and II) is now proposed till FY24 (extended recently by the Central government by two years) to support the market development of EVs.

Although the FAME I scheme could not fully utilize the sanctioned funds, it has provided the steppingstone for the uptake of electric mobility in the Indian market. The scheme was successful in creating awareness and momentum for electric mobility in the market. FAME phase II was issued in March 2019, with an increased layout of INR 10,000 crore. with a two-year duration from FY 2019-20 to FY 21-22. This scheme is majorly aimed to leverage the buzz created by its first phase to create a platform for the e-mobility sector to flourish in the country. Some of the critical gaps in FAME II are listed below:

A. **No incentive for vehicle scrappages/ Retro fitment allowance:** FAME II provided incentives for new EV purchase only and does not provide any scrappage incentive to encourage ICE vehicle owners to exchange their vehicle for getting EVs. Also, it does not mention any retrofit allowance for converting existing ICE vehicles to EVs.

B. **No mandate for EV adoption:** There is no EV mandate provided under the FAME II scheme, which resulted in the following issues: (i) insufficient development of charging facilities, (ii) investment dilemma among vehicle manufacturers.

C. **Absence of fee-bate concept:** Conventional ICE-based automobiles are more comfortable for users since they have been in use over a long time. This inertia developed among the consumers restricts the transition to EVs. The absence of the fee-bate concept in the policy, which allows putting huge fees/penalty/cess/surcharge in using ICE vehicles, may restrict the EV adoption due to this reluctance of users to convert from ICE to EV.

D. **Absence of subsidy for 4 W:** FAME II provides subsidy only for public 4W and not for private 4 W, restricting the transition of ICE based cars to EV.

E. **Requirement of re-certification:** To be eligible for getting demand incentives, OEMs must undergo a re-certification process for conformity check to obtain a certificate of 'FAME II India Phase II eligibility fulfilment' from approved testing agencies in India. The requirement of this certificate each year to claim the subsidy creates unnecessary administrative issues for OEMs.

F. **Requirement of Indigenous component:** As per FAME II guidelines, OEMs must use a certain percentage of indigenous components to avail subsidy. There is a need for a well-developed supply chain of auto components to have many EVs on the road, the absence of which makes the requirement of indigenous components act as a barrier. This will cause issues in getting incentives and trigger an increase in prices of EVs if OEMs try to import such components to fulfil the requirement.

AT STATE LEVEL

Table 11 summarizes the gaps and implementation challenges in EV policies of different states. Each state has unique requirements and policy focus on smart charging, as described in this section

Table 12: Summary of smart charging related gaps in Indian state EV policies[1]

	Key Point	DL	WB	KA	OR	MH	AS	AP	KL	BR	UP	GJ	TN	CH	MP	PB	TL	ML	UK	RJ
1	Incentivses for public charging infrastructure	#	×	✓	#	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×
2	Mandate on DISCOMs for establishing charging infrastructure	×	~	~	~	×	~	✓	~	×	✓	~	✓	×	✓	×	~	×	×	~
3	Incentives for residential/ workplace charging infrastructure	✓	×	×	✓	✓	×	✓	×	×	×	×	×	✓	×	×	×	×	×	×
4	Incentives for retrofitting of vehicles	✓	×	✓	✓	×	✓	×	×	×	×	×	×	×	×	✓	✓	×	×	×
5	Purchase incentive for EVs	✓	×	×	✓	✓	✓	×	*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	Public awareness program	✓	✓	×	✓	✓	×	✓	✓	✓	×	×	✓	×	✓	✓	×	×	×	×
7	Information on reimbursement of financial incentives	✓	×	×	✓	×	×	×	✓	×	✓	✓	✓	×	×	✓	×	×	×	×
8	EV specific tariff	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓
9	Land allocation/ concession for setting up the charging station	✓	✓	✓	✓	✓	×	✓	×	✓	✓	×	✓	×	✓	✓	✓	✓	✓	×
10	Focus on transitioning of government and public vehicles	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	×	×
11	Provision of R&D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	×	×	×

1 ×: Key attribute is not addressed in respective state EV policy, ✓: Key attribute is specified in the respective state EV policy,
~: DISCOM is not mandated but encouraged to invest in charging infrastructure, #: Provision for a capital subsidy for the cost of charger installation expenses to the selected Energy Operators
* Incentives only for 3 wheelers
DL: Delhi, WB: West Bengal, KA: Karnataka, OR: Orissa, MH: Maharashtra, AS: Assam, AP: Andhra Pradesh, KL: Kerala, BR: Bihar, UP: Uttar Pradesh, GJ: Gujarat, TN: Tamil Nadu, CH: Chandigarh, MP: Madhya Pradesh, PB: Punjab, TL: Telangana, ML: Meghalaya, , UK: Uttarakhand, RJ: Rajasthan (Policy draft under final stage, and concept paper)

While analysing the state EV policies from the viewpoint of smart charging, it was observed that the policies had specified some smart charging aspects, including communication and ICT technology. State-wise provisions related to smart charging is given in Table 13.

Table 13: Provisions related to smart charging

State	Provision related to Smart Charging
Delhi	• Time-of-use special EV tariff is implemented for controlled charging • To avail tariff concessions, chargers are expected to be connected to Central Management System with relevant DISCOMs to facilitate smart charging • The policy encourages the integration of RE generation. Energy Operator (EO) with captive RE generation would be given power banking facilities with the DISCOMs in Delhi for one year • EO are encouraged to accept payment via online modes such as mobile wallets, UPI, etc. • Transport Department, Government of National Capital Territory of Delhi (GNCTD) shall be developing a publicly-owned database of historical and real-time information of charging infrastructure
Karnataka	• Time-of-use-based EV tariff structure is implemented • Energy Supply Company (ESCOM) will examine the use of solar and low-cost renewable generation.
Maharashtra	• ToU tariff structure applicable to public charging stations performs smart charging based on time of use.
Andhra Pradesh	• Allows third-party EV charging providers to set up renewable generation at their premises. • Separate EV tariff based on peak and off-peak loading time is introduced. • The policy stated that Andhra Pradesh Regulatory Commission would issue a regulation and tariff structure for V2G power sale and ancillary support. • Cloud charging features are encouraged to have digital payment, metering.
Kerala	• Demand balancing in peak and off-peak hours using EV charging based on the time-of-use tariff structure is introduced.
Bihar	• Not mentioned
Uttar Pradesh	• Uttar Pradesh Regulatory Commission is planning to introduce a special power tariff policy based on the time-of-day sales of power for EVs.
Gujarat	• As per the Gujarat Electricity Regulatory Commission (GERC) order, the tariff will apply to third-party-owned EV charging stations.
Tamil Nadu	• EV charging service providers can install their own RE generation on their premises. • Supply of renewable generation will be made available to charging stations at zero connection cost on a preferential basis. • TNERC will determine tariff for EV charging stations strictly less than 15% of the average supply cost.
Madhya Pradesh	• Energy Operator should accept charging payment via online modes as mobile wallet, UPI, etc. • All charging stations should be linked to mobile applications to track, monitor, and record historical and real-time data. • Regulator commission of state will issue a tariff and regulation for V2G and ancillary support. • Public charging stations should be synchronised and store data into a publicly owned database. • Madhya Pradesh Urban Development and Housing Department (UDHD) has to create and maintain a database of public charging infrastructure through DISCOMS. • Net metering, digital transactions are encouraged via cloud-based charging features.
Punjab	• The policy makes available the option of a time-of-day tariff if required in off-peak hours. • Charging infrastructure operators using renewable generations are waived off from wheeling chargers.
Uttarakhand	Not mentioned
Telangana	• Supply of renewable energy (solar roof-top) with net metering in own premises of charging station is encouraged • A special power tariff for EV charging stations will get applied.
Meghalaya	• The state will provide attractive tariff for EV charging stations

State	Provision related to Smart Charging
West Bengal	• A public owned big database will be developed to provide real-time information on charging infrastructure. • Public charging points are synchronised and accessed freely from in-vehicle, mobile applications, and maps. • UPI based online payment platform is introduced. • Smart charging with V2G and integration of renewable energy generation will be explored.
Haryana	• The policy encourages RE-based charging and swapping station
Chandigarh	• Not mentioned
Odisha	• OERC will issue a separate electricity tariff. • Public charging stations will be encouraged to RE generation.

Table 14: Evaluation of charging infrastructure in different central and state policies

- 4 Not addressed
- 3 Partially addressed
- 2 Addressed up to reasonable extend
- 1 Fully addressed

Centre/States	Communication infrastructure	Protocols/ Standards/ Regulation		Aggregate smart charging Infrastructure with CMS/DISCOM	Conducive electricity market	Integration of Renewable/distributed generation	Provision of online payment and other services	Adequate focus on smart charging
		Commercial regulation	Technical regulation					
Centre FAMEII	4	2	2	4	4	2	2	4
MOP: charging guideline	4	2	1	4	2	4	2	4
CEA, DER regulation	4	4	1	4	4	1	4	3
Delhi	3	1	3	2	2	2	1	2
Karnataka	4	1	3	3	1	2	4	3
Maharashtra	3	3	4	3	2	4	4	3
Andhra Pradesh	2	1	3	3	2	3	2	2
Kerala	4	1	4	3	3	4	4	3
Bihar	4	4	4	4	3	4	4	4
Uttar Pradesh	4	1	3	4	3	3	4	3
Gujarat	4	3	4	4	3	4	4	4
Tamil Nadu	4	1	2	4	3	2	4	3
Madhya Pradesh	3	1	3	3	3	2	2	2
Punjab	4	1	3	4	3	3	4	3
Uttarakhand	4	4	4	4	4	4	4	4
Telangana	4	1	3	4	3	3	4	3
Meghalaya	4	3	4	4	3	4	4	4
West Bengal	4	4	3	3	3	2	2	2
Haryana	4	4	3	4	3	4	4	4
Chandigarh	4	4	3	4	3	4	4	4
Odisha	4	3	3	4	3	3	4	3

**This analysis of state EV policies is conducted as of August 2021.*

Analysis of the provisions related to smart charging in different state policies and the evaluation of charging infrastructure from the perspective of smart charging given in Table 13 and Table 14 depicts that the underdeveloped and incipient communication infrastructure and inadequate central management system infrastructure forms the major disparity between existing charging points and smart charging-enabled charging points. Immature regulation framework and conducive EV market to leverage the benefit of smart charging are other potential reasons for the lack of smart charging infrastructure. The overall state-wise policy modification requirement for smart charging, communication and ICT perspective is given below:

4.1 Interventions Required in Policies for Smart Charging, Communication, and ICT

1. DISCOMs should provide initial logistic support (viz, network information, access to required data, historical data of load, etc.) to implement a smart charging station.
2. Mandate Government offices/PSUs to establish smart charging stations in the respective region and offices.
3. Provide financial incentives and land support for establishing a smart charging station.
4. Subsidise the procurement of metering equipment, required software, and communication networks required for smart charging.
5. Issue reward points or green certificates to EV owners using the smart charging option and charging their vehicles for more than pre-set aggregated charging energy (kWh). Allow free parking at government parking spaces against green certificate and provide concession in electricity bill against reward points. It gives priority to government-owned public charging stations for eligible EVs.
6. Incentivise the solar PV installation and integration at home, society, public, and private charging stations.
7. Encourage local smart charging for using the locally controlled smart charging station by providing a small rebate on the monthly charging bills.
8. Mandate relevant agencies to create a complete package of required logistics, software, network service providers, and training material. If a charging station owner wishes to opt smart charging strategy, he could directly avail of this complete package and establish a smart charging station.
9. Provide special incentives for retrofitting older charging stations and fuelling stations with smart charging stations. Exempt the retrofitted stations from availing support provided in point 3.
10. R&D funds should be allotted for research in the field of Vehicle-to-Grid (V2G) integration for national transportation, EV, and grid scenario.
11. Run awareness programs to spread the benefits of EV, state's EV policy, and smart charging in reducing electricity bills and environmental welfare.
12. Prioritise the approval, land allocation, and incentives to smart charging stations over dumb charging stations.
13. Mandate to establish and retrofit all the charging stations in government spaces and commercial, public charging stations to be smart, based on a time-of-use tariff.

14. Allot incentives to purchase smart charging software and services such that it attracts the charging station operator.
15. Security standards should be structured or adopted from any standard organisation to safeguard the user's, charging station's, metering, and sensing equipment's data to maintain users' privacy and charging stations to avoid cyber threats on users or charging stations.
16. Communication network protection standards should clearly mention protecting the data while communicating over the network.
17. Investigation of vulnerable nodes in the system must be done regularly.
18. Grant R&D projects to investigate and develop modern information and communication technology (ICT) based integration and smart charging techniques for EV ecosystem in the presence of EV loads, smart grid, renewable generation, and digital billing.
19. Introduce smart charging and ToU incentive for residential EV customers. In this scheme, eligible customers will get an instant rebate of the appropriate amount for participating in this smart charging such that respective residential customers get a charge at a lower price as per time-of-use according to availability of cleaner and cheaper energy (Alternative Fuels Data Centre: Smart Charging and Time-of-Use (TOU) Incentives - Orange & Rockland Utilities (O&R)).
20. Allow private players to provide EV owners and fleet operators special offers for buying and participating in their smart charging using ToU or any other strategy.
21. Incentivise eligible EV customers for participating in various pilot projects and case studies in due course of time (Alternative Fuels Data Centre: Plug-In Electric Vehicle (PEV) Charging Study Incentive - Tacoma Public Utility (TPU)).

PART- B

Technical review of various EV smart charging strategies

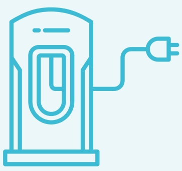
The charging strategy is selected based on the computational and communicational infrastructure. Computational infrastructure is related to arithmetic or logical processing units viz. CPUs and central processors whereas communicational infrastructure are the devices or networks used for communication of various needed information or data.

05

Introduction to Smart charging approaches and strategies

EV smart charging is necessary to manage the charging demand with the available grid infrastructure and generation capabilities. It plays a vital role in achieving different objectives, such as cost minimization, loss minimization, congestion management, grid support and grid stability, depending on the type, preferences, and required infrastructural and computational capabilities of consumers. Designated charging strategies are mostly categorized based on the location of an EV charging station rather than the type of EVs in particular. The primary reason for using a smart strategy is that it provides an opportunity to use optimized charging considering grid parameters and the owner's choice. Another reason for using these strategies is that the need for infrastructural upgradation can be reduced, delayed, and the cost for additional mandatory infrastructure upgradation can be recovered quickly. The electricity tariffs for EV charging are often based on time-of-use or dynamic pricing. Based on the pricing, the local charging strategy uses a time-of-use type of tariff, whereas the other strategies use dynamic or time-of-use tariffs.

EV charging particularly has three stakeholders: the system operator, the EV owner, and the aggregator defined in section 2.2 (Wang et al., 2016) in this report. The aggregator is a coordinator between the system operator and EV owner/user. Its role is to charge the EVs so that the system operator can maintain the key operational network parameters within an allowable range, while optimising the charging cost for EV owners. Each stakeholder has its desired objectives, and smart charging is the way to find the best solution considering all requirements and constraints. Figure 58 provides a basic structure of smart charging strategies considering the stakeholders involved, smart charging objectives, strategies, and the location.



The charging strategy
is selected based on the computational and communicational infrastructure

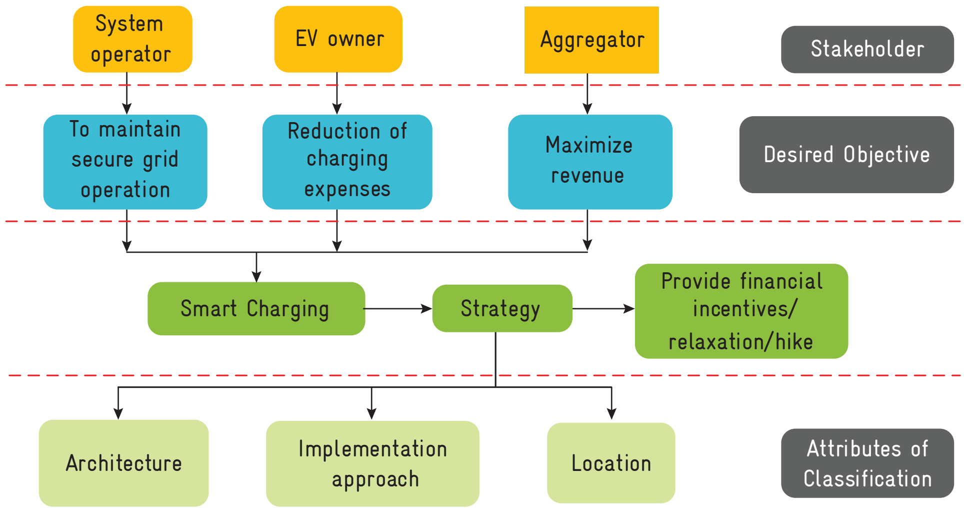


Figure 58: Motivation for smart charging

Designated charging strategies are mostly categorized based on the location of an EV charging station rather than the type of EVs in particular.

The charging strategy is selected based on the computational and communicational infrastructure. Computational infrastructure is related to arithmetic or logical processing units, i.e., CPUs and central processors. In contrast, communicational infrastructure comprises the devices or networks used to communicate various needed information or data. For additional low-cost and computational infrastructure, the local charging strategy is a better option. For medium-cost and computational infrastructure, decentralized, distributed, and hierarchical strategies are used since it distributes the computational burden among all the participating entities rather than concentrating on a single unit. The classification of the smart charging strategies based on topology/architecture, location, ownership, methodology/approach, and price structure is shown in Figure 59.

Part B of the report covers EV charging strategies based on control architecture and objectives in Chapters 6 and 7. Chapter 8 discusses optimization algorithms used to implement smart charging; Chapter 9 focuses on the artificial intelligence/machine learning-based approach for smart charging, whereas price-based EV charging coordination methods are described in chapter 10. Fleet control and charging station coordination are documented in Chapters 11 and 12, respectively.

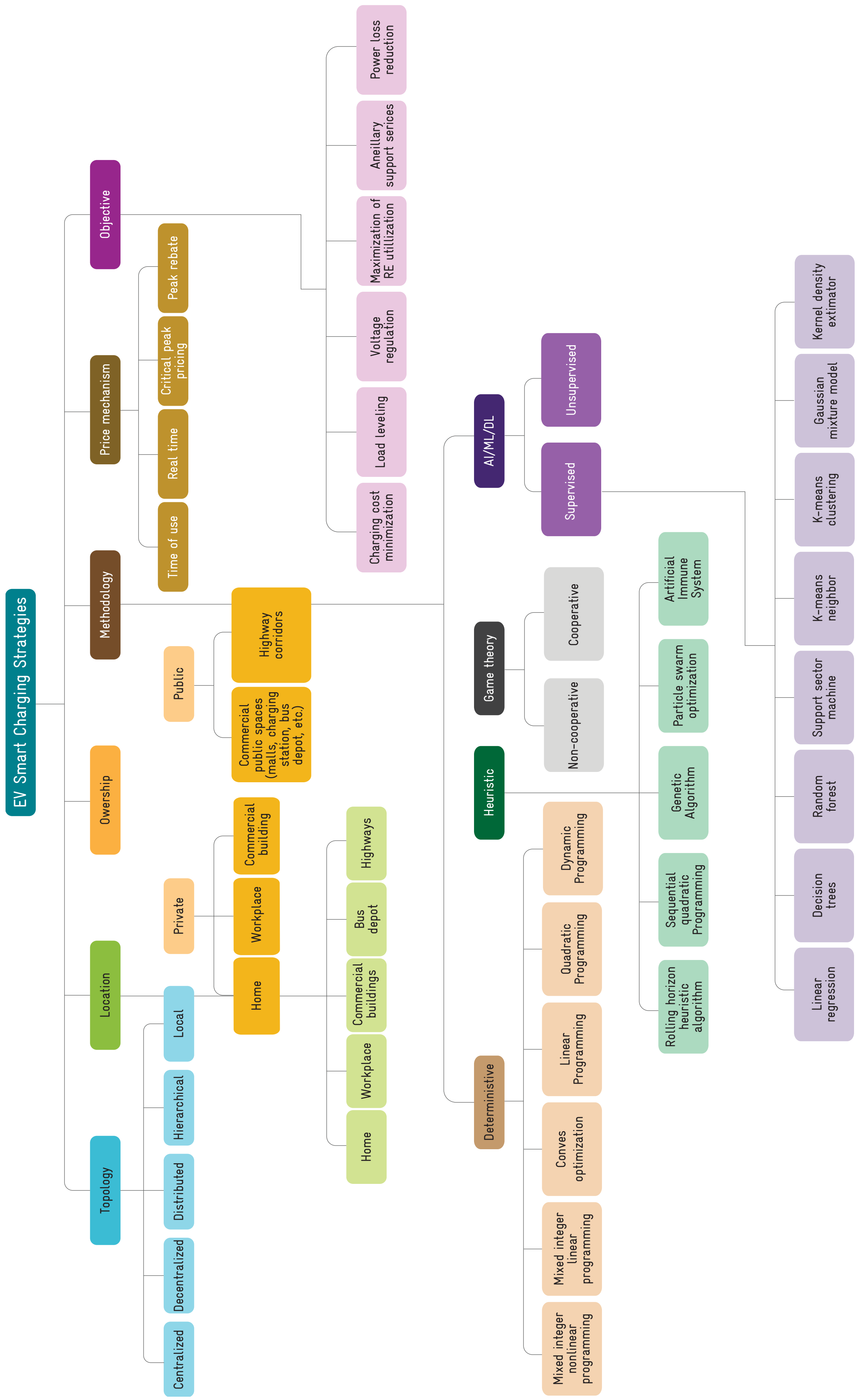


Figure 59: Classification of Smart Charging Strategies based on different attributes

06

EV Charging Strategies Based on Control Architecture

EV charging strategies can be categorized based on the control architecture of smart charging, which can be divided into five categories: centralized control, decentralized control, distributed control, hierarchical control, and local control. The network operator, aggregator, and EV owners are directly involved in almost all the strategies, except the local strategy where the EV user is primarily involved. The different control architecture schemes for smart EV charging are described below:

6.1 Centralized Control Based Strategy

In this strategy, the aggregator decides the pattern for EV charging within its contract by considering the system operator's constraints and the charging energy requested by the EV owner. As shown in Figure 60, the information signal for the energy request from the owner flows from the EV owner to the aggregator (Nimalsiri et al., 2020). The aggregator's role in the strategy is to maintain the system while fulfilling the energy demand of the EVs. All the charging decisions are taken by the aggregator, which entails the requirement of higher computational power. To quickly address the energy requirement of the EVs, the strategy requires high-bandwidth communication.

In the early developing stages of EV ecosystem, system operator plays the role of aggregator due to the absence of an active aggregator.

In all the EV charging strategies mentioned in Figure 59, the grid operator allots the charging capacity to an aggregator as per the charging requests from aggregators and available power supply. The decision signal always flows from grid operator to aggregator and information signal from aggregator to system operator. In the early developing stages of the EV ecosystem, the system operator plays the role of the aggregator due to the absence of an active aggregator.

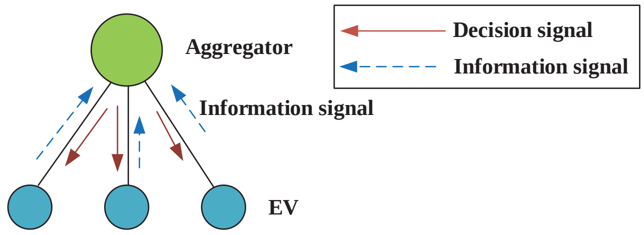


Figure 60: Centralized control strategy

The controlling unit in the centralized control does not permit the plug-and-play mechanism, which might discourage the owners due to the lack of assurance on immediate starting of EV charging. The decentralized control architecture overcomes the issue of uncontrolled charging from the EV owner's perspective. The advantages and disadvantages of centralized control architecture are listed below:

Advantage

1. Facilitate direct control on global network constraints.
2. Find an optimal solution considering all the stakeholders.
3. Take care of faults and congestion in the system.

Disadvantage

1. Affects the complete charging system if a fault occurs on the central unit.
2. Less flexible
3. Relatively low reliability

6.1.1 CENTRALIZED EV CHARGING COORDINATION

In this type of strategy, all EVs are coordinated via a central unit. The main objective of the aggregator as the central unit is to optimize the charging schedule and push the system towards a global optimum. In a central coordination scheme, all the participants are contractually bound to an aggregator. This central entity pursues to make the system achieve the global optimal value considering system constraints specified by the distribution system operator and individual EV owners. In this coordination strategy, the aggregator controls the value of the charging power. This optimal value of charging power varies based on the system constraints (Gonzalez Vaya and Andersson, 2012) and the cost of electricity (Gan et al., 2013). As mentioned in the following representative cases, the charging power depends greatly on the objective function and the associated constraints.

Case 1: The objective function, in this case, can be the minimization of charging cost by considering the constraint of maximum available power from the system operator. The optimal solution of the problem schedules the lowest amount of charging power/energy at daytime and maximizes the amount of charging power/energy at night-time after the evening peak.

Case 2: The objective function, in this case, can be charging cost minimization while considering the maximum utilization of renewable energy. The problem solution provides an optimal schedule for the maximum charging power during daytime when RE generation is higher (due to solar PV) and less charging power at night-time.

Case 3: The objective, in this case, can be minimization of the distribution transformer losses and its loading considering voltage profile and line loading as a constraint. The optimal solution, in this case, schedules the higher amount of charging power after the daytime peak and lower charging power for the peak load period. The same pattern of charging power is repeated in the evening time such that during the evening peak period, the charging power is low, and after the peak period ends, it is comparatively high.

From the above three example cases, it is clear that the central unit executes the optimization problem and schedules the EV charging in terms of varying values of charging power. It validates the fact that the central level EV coordination determines the optimal global solution. The optimal global solution in EV smart charging context is the best EV charging schedule that satisfies objective function and maintains constraint parameters within bounds. The central coordination among the EVs is performed in particular time slots, which varies in different networks. Centralized EV coordination is again classified based on the time of performing the optimization. Day-ahead optimization is the first type in that central unit that coordinates EVs a day before the actual scheduling. Based on day-ahead scheduling, the system operator can conveniently dispatch the power in a flexible manner. The second type is the real-time EV coordination which coordinates EVs considering the roaming of EVs and deviation of EVs from their schedule and uncertainty in the EV charging time.

The central coordination for EV charging can be achieved through different methods, such as fuzzy control, model-predictive control, different optimization methods, and ML/AI/data-driven methods.

The charging schedule is prepared based on network constraints and local parameters. For coordination of the EV charging at the central level, fast communication infrastructure is required. The central coordination for EV charging can be achieved through different methods, such as fuzzy control, model-predictive control, different optimization methods, and ML/AI/data-driven methods. Centralized EV coordination can further be differentiated based on the smart charging objective and optimization constraints. In the following subsection, the centralized control strategy is further described in detail.

6.1.2 CENTRALIZED CONGESTION MANAGEMENT

Distributed energy resources like EVs can potentially support and stress the grid during periods of peak demand. For example, suppose EV charging is not coordinated while considering grid constraints. In that case, there could be adverse impacts on the grid in terms of overloading the system and line congestion due to the peak overlap of residential and EV charging load. Coordinated EV charging as per grid requirement can support grid stability and avoid/minimise line congestion, thereby reducing the stress on the grid. In one of the coordinated charging strategies, EV charging is shifted to off-peak hours and energy-rich generation hours such that power flow through the lines does not violate the line thermal rating. Further details on congestion management are discussed in (Hu et al., 2014).

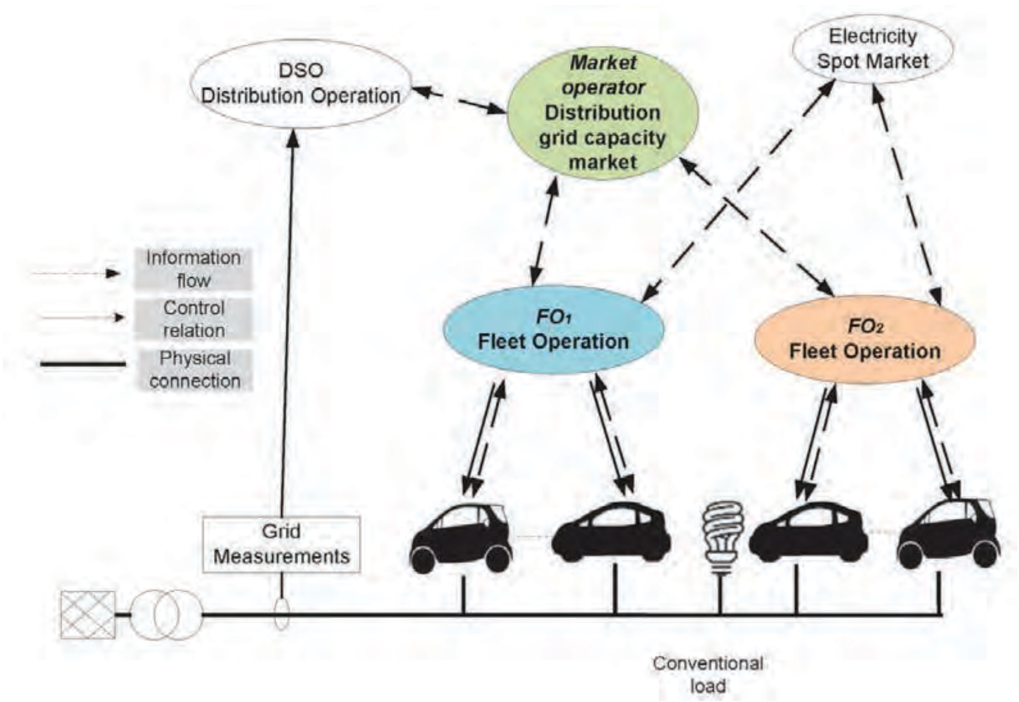


Figure 61: Network architecture of low voltage distribution system (Hu et al., 2014)

Coordinated EV charging as per grid requirement can support grid stability and avoid/minimise line congestion, thereby reducing the stress on the grid.

In (Hu et al., 2014), the coordination between distribution system operator (DSO) and fleet operator (FO) or aggregator has been used to handle the congestion issue. Distributed grid capacity market has been used for congestion management. Further, the study combines the day-ahead electricity market and the state of the distribution grid to minimize congestion in the system.

The network architecture used in the study is shown in Figure 61, where there is an established bidirectional information flow between the distribution market operator and the electricity spot market with the fleet operator or aggregators. FO and EVs are also connected through bidirectional information flow and unidirectional control flow from the former to the latter.

The market-based congestion approach uses costs associated with controlled power dispatch and the desired power. The objective function for congestion management is expressed as cost minimization between the cost of controlled power and the cost of required power, as shown in 0 1.

$$min \sum_{k=1}^{N_B} \sum_{i=1}^{N_T} C_{k,i} \left(\tilde{P}_{k,i} - P^E_{k,i} \right)^2$$

$C_{k,i}$ denotes the weight factor associated with the power difference. A higher $C_{k,i}$ represents smaller power differences. $P^E_{k,i}$ is Power requirements of EVs of each FO in each time slot. $\tilde{P}^E_{k,i}$ is the controlled power variable decided by considering the distribution capacity of the system at the respective time slot. The constraint condition for controlling the power within the distribution power capacity is given in 0 2.

$$\sum_{k=1}^{N_B} \tilde{P}_{k,i} \leq P_{cap}(i)$$

P_{cap} is the aggregated power capacity of fleet operators. The problem formulated above is convex in nature. Hence, it is transferred into Partial Lagrangian problem in 0 3, due to which the centralised problem is transformed into a decentralised format using shadow price of Langrangian multiplier $\gamma(i)$.

$$L = min \sum_{k=1}^{N_B} \sum_{i=1}^{N_T} C_{k,i} \left(\tilde{P}_{k,i} - P^E_{k,i} \right)^2 + \sum_{i=1}^{N_T} \gamma(i) \left(\sum_{k=1}^{N_B} \tilde{P}_{k,i} - P_{cap}(i) \right)$$

This optimisation problem is solved using the sub-gradient method. The flowchart of the proposed method with shadow cost is shown in Figure 62. It shows that the initial value of the shadow price is zero, and the algorithm continues until the shadow price limits fall below zero. Based on the updated shadow price in each iteration, the charging profile is also updated.

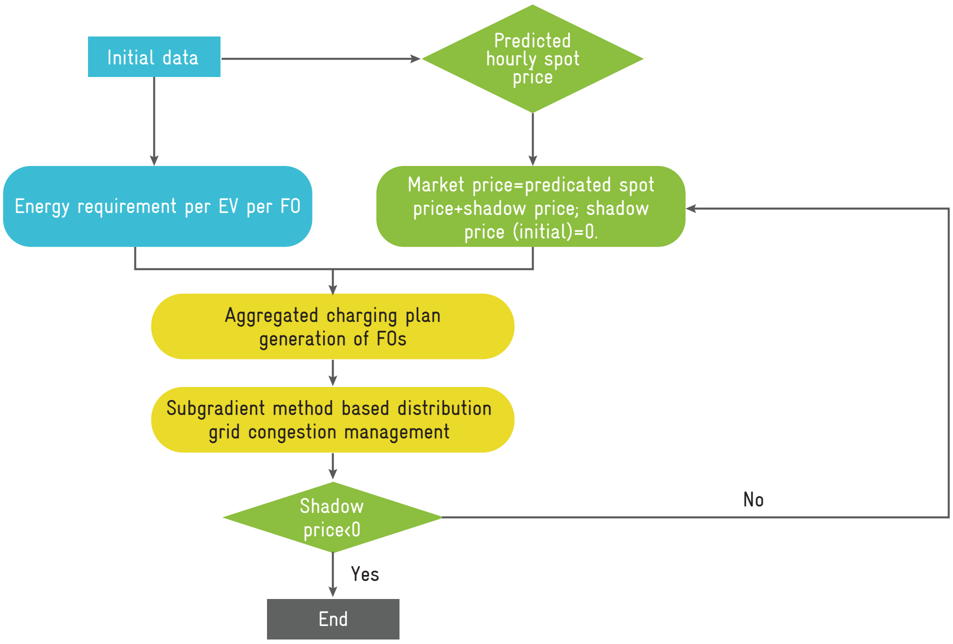


Figure 62: Flowchart of the proposed method (Hu et al., 2014)

A case study is performed considering sixty householders connected to the feeder, out of which 60% of households have EVs integrated and connected with FO1 and FO2 (Hu et al., 2014). Figure 63 shows the spot price curve of a day that indicates that the electricity prices are low during morning hours compared to other times.

Figure 64 shows the energy schedule for charging FOs and the demand of 18 customers connected to FOs. It can be observed that the aggregated demand of individual FOs is concentrated in the daytime. It depicts that most of the charging is scheduled during the early morning because of low spot prices considering system capacities and eliminating line congestion.

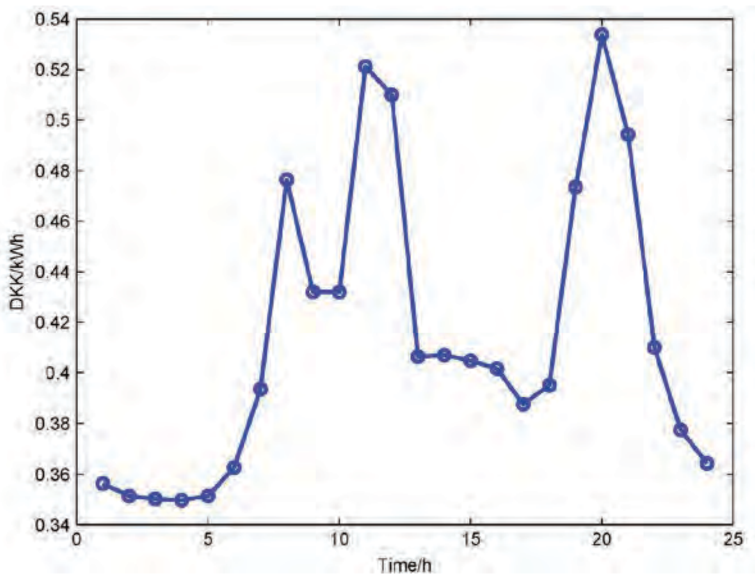


Figure 63: Spot price curve of a day (Hu et al., 2014)

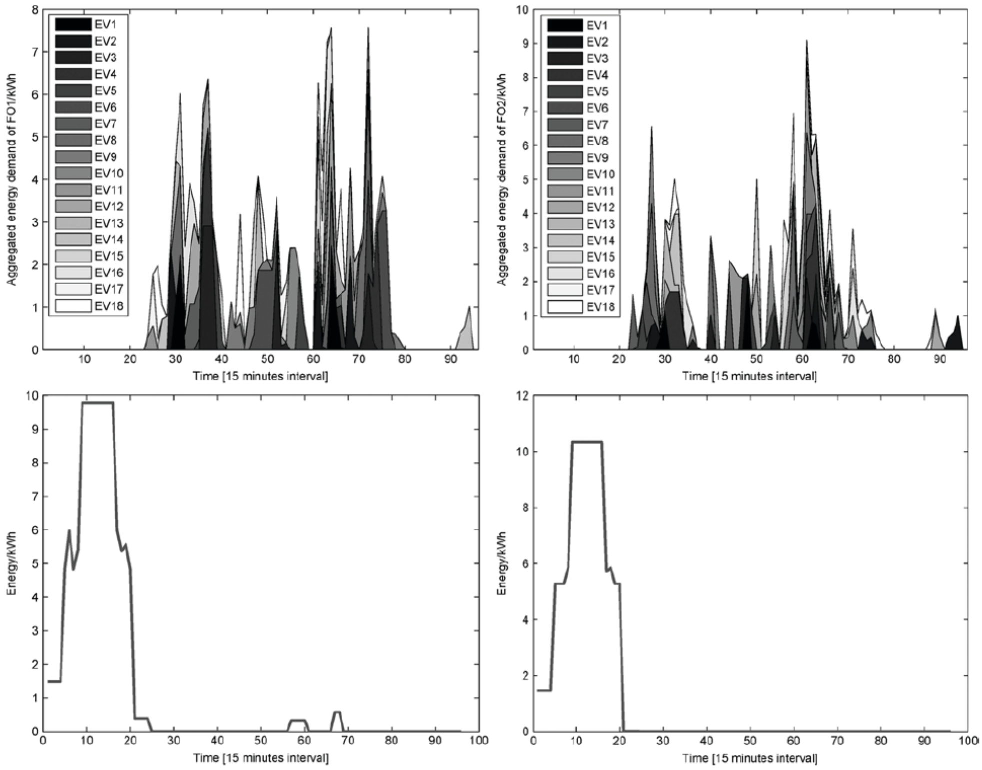


Figure 64: **Top: Aggregated energy demand of fleet operator 1 and 2, Bottom: Aggregated energy schedule of fleet operator 1 and 2 (Hu et al., 2014)**

Results shown in Figure 65 depict the capacity surface at each time slot and the scheduled power. It also indicates that the scheduled power is breaching the power capacity limit at starting iterations, which leads to congestion. However, in the later iterations, power is scheduled uniformly, so that demanded power does not violate the power capacity limits, which ensures there is no congestion in the system.

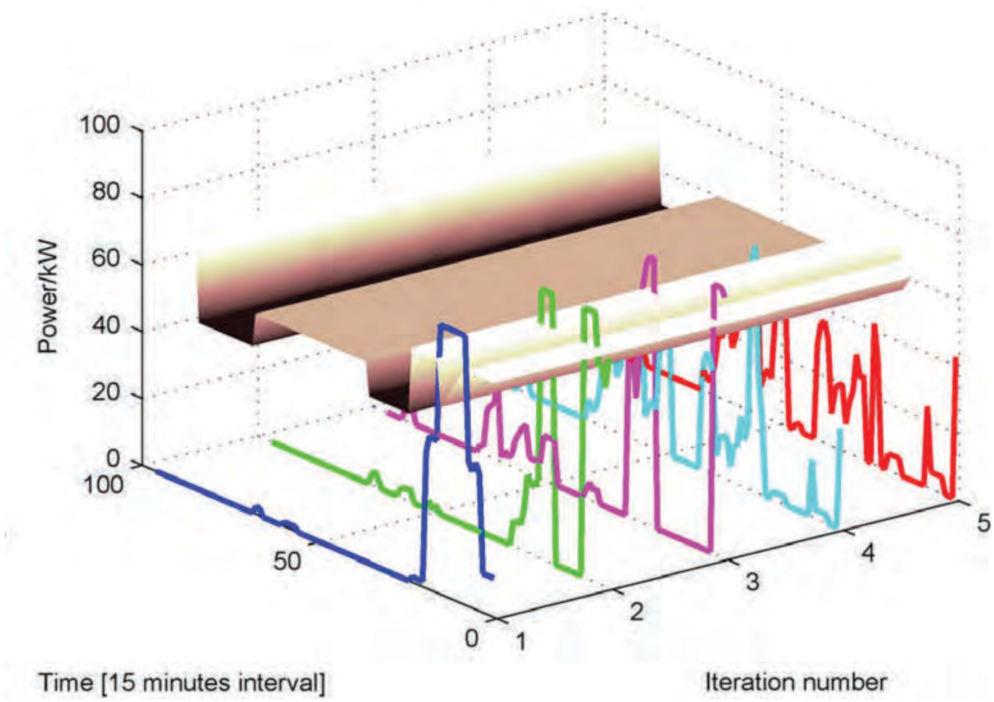


Figure 65: **Comparison of fleet operator power with maximum power capacity (Hu et al., 2014)**

6.2 Decentralized Control Based Strategy

It requires less computational power because of the shift in the decision-making entity from the aggregator to the individual EV owner.

In decentralized control architecture, the EV owners decide EV charging. Simultaneously, the aggregator/system operator indirectly tries to influence the decision of the EV owners by offering incentives, varying electricity prices, potential revenue etc. (Gan et al., 2013). As shown in Figure 66, the information signal carries the aggregator's real-time prices dataset to control the EV charging indirectly. It requires less computational power because of the shift in the decision-making entity from the aggregator to the individual EV owner. This control architecture provides a plug-and-charge facility to the users, and it is relatively popular among EV customers. However, unlike the centralized control architecture, the decentralized charging approach does not guarantee the global optimum solution for the system.

Advantage

1. It facilitates a simple plug and charge mechanism.
2. Charging system will continue working even if a fault occurs at the central level.
3. Relatively higher overall reliability.

Disadvantage

1. Unable to accommodate network constraints in charging decisions.
2. It does not guarantee the optimal solution.
3. It does not allow direct control of charging power, which influences the system stability.

The limitation of system stability issue in the decentralized control is addressed in distributed control.

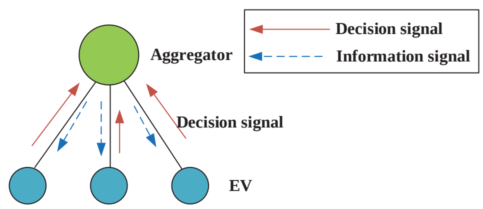


Figure 66: Decentralized control strategy

6.2.1 CHARGING COORDINATION VIA NON-COOPERATIVE GAMES

In practice, many EV participants try to adopt a strategy to maximize their profit by minimizing the electricity cost. However, it does not guarantee the global minimal electricity cost compared to other participants. Such a non-cooperative strategy cannot maintain the grid requirement and may lead to grid overloading. A game theory approach is introduced in (Yanni Wan et al., 2021), which considers this adverse effect of an individual strategy setting and uses the information of all the participants' strategies to find the global optimal solution. Based on the concept of considering an individual participant's strategy in the problems space, this game theory approach is divided into two methods.

The first approach is cooperative game theory. All participants decide their strategy mutually to reach the optimal solution and for the system to reach the global optimal position. Once the global and optimal strategy is defined, the system rests in the global state until the next move from any participant. In this method, a deviation of one participant from its optimal strategy changes the global optimal.

Decentralized charging based on fixed prices or dynamic prices will not give an optimal solution.

The second approach is the *non-cooperative game theory*. In this case, every participant is free to decide its strategy to obtain a personal profit. In addition to this, a participant considers the strategy of the other players as well. As all the participants decide their strategy considering the other participants' strategy, the system will reach a state of equilibrium known as Nash equilibrium. At the Nash equilibrium point, a deviation of any participants from its strategy does not affect the optimal solution of the system (Zhao et al., 2020).

The non-cooperative game theory approach exceedingly resembles the EV charging problem's actual nature considering both EV charging problem strategies (Y. Wan et al., 2021).

In the actual EV charging problem space, EV owners are the participants. The aggregator is a controlling agent that tries to push the system towards a global optimal equilibrium point in both cooperative and non-cooperative approaches. The role of the aggregator is different in both methods. In the cooperative game theory approach, the aggregator's role is to gather the information of an individual's strategy and communicate them an optimal strategy, which will lead towards the global optimal solution (Shakerighadi et al., 2018). In the non-cooperative game approach, the aggregator tries to indirectly influence the participants' strategy so that the system reaches the Nash equilibrium.

In a real charging scenario, participant's behaviour varies all the time, so the non-cooperative approach is considered a preferable option (Tan and Wang, 2016), (Wan et al., 2020), (Zhao et al., 2020) to ensure that the behaviour of individual participant does not affect the equilibrium of the system. While deciding the actual strategy for EV charging, two scenarios, viz., a large EV population and infinite EV population, need to be taken into special attention to meet the ideal condition of the charging scenario. These conditions are modelled mathematically in the literature (Wan et al., 2020), (Zhao et al., 2020).

6.2.1.1 Decentralized Charging Coordination of Large EV Population

High networking and computation power are required in a centralized strategy that may have problems in gaining the acceptance of EV owners, so the decentralized strategy is majorly implemented in the literature (Zhao et al., 2020). Each player (EV) tries to minimize its own cost without cooperating with others in actual charging conditions. This scenario is modelled as a non-cooperative game problem. When players adopt the strategy without considering others' strategies, the system will reach a suboptimal point. To find the optimal solution using a non-cooperative game, each player has to decide on its optimal strategy considering all the other players' strategies. In this strategy, the decision for charging is taken by the EV. Hence, the non-cooperative decentralized charging strategy is applied.

A decentralized non-cooperative game approach optimizes the system to achieve different stakeholders' objectives.

Decentralized charging based on fixed prices or dynamic prices will not give an optimal solution. For making this decentralized charging an optimal solution, a non-cooperative game strategy is used as a local controller to find the optimal solution for a large EV population (Ma et al., 2016). In this approach, EV owners take charging decisions in a decentralized manner. An aggregator tries to influence the charging strategy of the participants and drag the system towards Nash equilibrium.

A decentralized non-cooperative game approach optimizes the system to achieve different stakeholders' objectives. Cost minimization, valley filling, and load levelling are the main objectives achieved using the decentralized non-cooperative game theory approach. In some cases, utility plays the role of an aggregator. The influencing element in the decentralized non-cooperative game approach is electricity cost.

6.2.1.2 Decentralized Charging Coordination of Infinite EV Population System

In an ideal case, a control strategy should work for an infinite EV population. However, when infinite electric vehicles are present in the system, the effect of an individual EV strategy on the average EV strategy will be negligible.

As mentioned above, an individual EV updates its strategy considering the population's average strategy by averaging all other participants' strategies. In an ideal case, a control strategy should work for an infinite EV population. However, when infinite EVs are present in the system, the effect of an individual EV strategy on the average EV strategy will be negligible. This negligible change in average charging strategy due to deviation in any EV's charging strategy will lead to no variation in the individual charging strategy. In such a situation, local optimal strategies control the Nash equilibrium when the local charging strategy equals the common average charging. The average of all the charging strategies is equal to the common charging strategy. From the first look at the non-cooperative algorithmic concept, it is apparent that it will be time-consuming because of the required updates. However, in the actual procedure of finding Nash equilibrium, simultaneous strategy update of individual Evs based on the average charging strategy of other Evs reduces execution time.

The following steps describe the approach of this particular decentralized non-cooperative approach:

1. Divide the infinite population into small groups and collect the information of the average strategy of the groups.
2. Individual EV in a group of 'N' EV implements the individual best strategy to find the optimal solution
3. Update the strategy of individual EV by the influence of the average strategy of the subpopulation group
4. Repeat steps 2 and 3 till the strategies stop updating
5. Repeat steps 2, 3, and 4 for all subpopulation groups successively.

For the application of a decentralized non-cooperative strategy for an infinite EV population, Nash equilibrium is iteratively computed. The individual EV charging strategies are allowed to update the best possible ones for the whole EV population's behaviour. This procedure was applied successively to find the optimal NE (Yin et al., 2011).

6.2.2 DECENTRALIZED CHARGING COORDINATION WITH BATTERY DEGRADATION COST

Decentralized control motivates the customer to perform smart charging to minimize the electricity cost, to name a few desired objectives. The battery is at the heart of the EV, and its degradation reduces the lifecycle of an EV battery. Hence, ensuring a prolonged battery life while performing smart charging is an important aspect. Equivalent battery cost is introduced in the mathematical smart charging problem to incorporate the objective of battery life (Bordin et al., 2017), (Saldaña et al., 2019).

A battery is continuously degrading when used, which means a battery is constantly degrading during every charging and discharging cycle. Based on this phenomenon, battery degradation cost is associated with three operations, the first being normal charging or discharging mode, the second being transition within modes, and the third being the cost associated with depth of discharge. Battery degradation cost due to charging and discharging operation is also called battery degradation cost per kWh. This cost is associated with the outward energy flow through the battery. The general assumption is that when the battery's energy supply capacity (throughput) is equal to the battery's lifetime energy supply capacity, the battery needs to be replaced. This cost function is defined in (0-1) (Bordin et al., 2017):

Battery degradation cost is associated with three operations, the first being normal charging or discharging mode, the second being transition within modes, and the third being the cost associated with depth of discharge.

$$C_{kWh} = \frac{C_{Rep}}{L_{bat} * E} \tag{0-1}$$

Where, C_{Rep} is the replacement cost of the battery, C_{kWh} is the battery degradation cost per kWh, L_{bat} is the lifetime throughput of the battery, E is the square root of efficiency. The cost mentioned above is associated only with battery discharging.

The cost associated with every depth of discharge cycle is given below (0-2)

$$C_{dept} = \frac{R}{D_n} \tag{0-2}$$

Where C_{dept}: the cost associated with each depth of discharge cycle, R: capital battery cost, D_n: Number of the depth-of-discharge cycle remaining to fail the battery.

The third cost associated with battery degradation is the cost frequency transition between charging-discharging modes. Frequent battery charging-discharging costs can be determined using model parameters. These costs are an important part while minimizing the objective of charging costs.

6.2.2.1 Decentralized EV Charging Coordination Method with Fixed Energy Demands

For a fixed demand of energy, the coordination of decentralized charging is simple. In a fixed energy requirement, the battery degradation cost can be represented as a flat charging schedule, which smoothens the charging as smooth as possible (Liu et al., 2017). A fixed amount of energy flows inside and outside the battery for fixed energy demand, minimizing the cost per kWh. It also reduces the depth-of-discharges as an EV owner can schedule the charging in advance.

6.2.2.2 Decentralized Methods with Flexible Energy Demands

Flexible energy demand needs a variable charging profile, which will increase the battery degradation cost per kWh. Uncertain flexible charging demand increases the chance of depth-of-discharge and the number of charging/discharging cycles. Battery degradation cost is important in terms of the flexible energy demand. Due to the flexible demand, the battery degradation cost increases and the battery life is decreased.

A local controller is considered a better choice for minimizing battery degradation cost. A local strategy considers individual information of the battery and local network parameters, and it is easy for the controller to track the information of a single battery.

A local controller is considered a better choice for minimizing battery degradation cost. A local strategy considers individual information of the battery and local network parameters, and it is easier for the controller to track the information of a single battery. In control strategies other than local strategy, it is challenging to consider and keep track of the battery degradation cost of the individual battery (Latifi et al., 2019).

6.2.3 DECENTRALIZED CHARGING AND DISCHARGING COORDINATION

As mentioned in the above section, the EV owner takes a charging decision in a decentralized manner, and the aggregator communicates the charging and discharging price to the EV owner (Wang et al., 2016). The EV owner also communicates the electricity demand to an aggregator. By considering the electricity charging demand, the aggregator updates the electricity cost in proportion to the charging demand and discharging requirement (Gan et al., 2013). To achieve charging-discharging coordination in this decentralized approach, the aggregator provides their respective prices. Aggregator reduces the charging cost when there is sufficient power available while complying with the other network constraints. When the system requires power from EVs, the aggregator increases the price for providing the energy. When the system does not require the discharging power from EV, the aggregator reduces the discharging cost. The aggregator indirectly pushes the EV owner to charge or discharge by increasing or decreasing the energy cost for charging and discharging while observing the individual profit from reduced and increased costs.

The studies reported in (Gonzalez Vaya and Andersson, 2012) (Xing et al., 2016) have used local controllers for charging and discharging in a decentralized mode. This decentralized local controller is used to solve specific problems like reducing load variation and load flattening. This is another decentralised control approach in which the local controller takes charging decisions and communicates them to the aggregator.

This type of local controller-based decentralized strategy coordinates EV charging and discharging according to the price signal provided by the aggregator and decision objective. Optimal coordination between charging and discharging using a local controller in a decentralized strategy reduces the computational burden of distributed computation at the individual EV owner level. In (Xing et al., 2016), the optimal load scheduling problem is formulated as Mixed Discrete Programming (MDP). MDP is used to solve optimization problems with both continuous and discrete variables present in the problem. This problem is an NP-hard problem, i.e., the problem is at least as hard as any NP (Non-deterministic polynomial-time) problem to solve. That is why an approximated MDP is formulated to solve the optimal charging-discharging coordination problem. The approximation of the MDP method uses the shape of the base demand curve at night that divide the time range for charging or discharging. The formulated problem is solved using an iterative water-falling mechanism implemented at the local controller to reduce computation burden (Xing et al., 2016). In such a decentralized strategy, only the customer's decision for charging or discharging is communicated to the aggregator over bidirectional communication. So, the strategy maintains customers' privacy.

6.3 Distributed Control Based Strategy

Distributed control is the advanced version of decentralized control as the EV owners take the decisions in it. In contrast, the aggregators communicate among themselves, as shown in Figure 67, to find the optimal operating point considering the maintenance of system stability (Nimalsiri et al., 2020). This control benefits the system reliability as it continues charging operations if any fault occurs in the central unit.

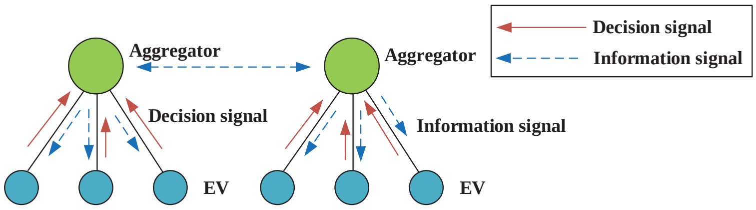


Figure 67: Distributed control strategy

Advantage

1. Improves system stability by establishing the communication between aggregators.
2. It ensures plug and charge mechanism, which encourages participation of EV customers in smart charging.
3. Relatively higher overall reliability.

Disadvantage

1. It does not allow to maintain system constraint limits directly at central level.

6.3.1 DISTRIBUTED POWER PROFILE TRACKING FOR HETEROGENEOUS CHARGING OF ELECTRIC VEHICLES

(Malhotra et al., 2017) proposes a distributed strategy for tracking heterogeneous charging profiles. Heterogonous power profile tracking is possible with a centralised and hierarchical strategy as well. In a centralised and hierarchical strategy, a centralized aggregator is present who coordinates all the charging behaviour. In case the central aggregator fails, all EVs will become uncontrolled. For avoiding this, a distribution strategy is introduced, which eliminates the need for the central aggregator.

Instead of a central aggregator, sub-aggregators are virtually connected via communication links to track the heterogeneous charging. A conceptual diagram of sub aggregators in a distributed strategy is shown in Figure 68.

For problem formulation, the charging horizon is discretized into time slots of 15 minutes each. The number of EVs to be charged is given by N, the number of sub-aggregator (SA) is k, and the number of EV connected to k-th SA is denoted by N_k. The proposed strategy can maintain grid constraints and maximize users' convenience.

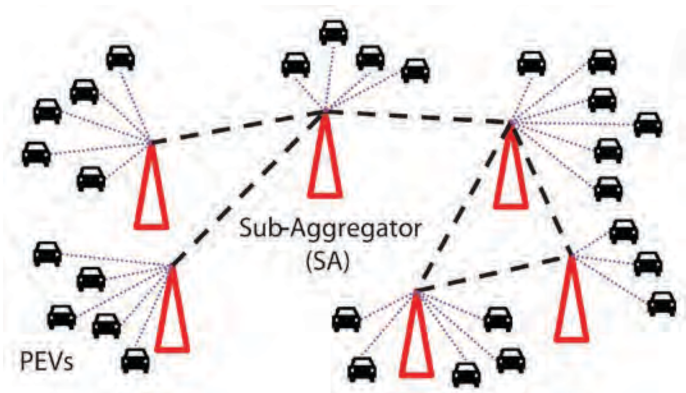


Figure 68: Proposed sub aggregator system with sub-aggregator (Malhotra et al., 2017)

The objective of this strategy given in 0-1 is to maximize the user's convenience shown in the equation.

$$\max J = \sum_{k=1}^{K} \sum_{i=1}^{N_k} J_{i,k} L_{i,k} s_{i,k} \qquad \text{0-1}$$

subject to,

$$\sum_{i=1}^{N_k} s_{i,k} L_{i,k} \leq P_k \qquad \text{0-2}$$

$$\sum_{k=1}^{K} \sum_{i=1}^{N_k} s_{i,k} L_{i,k} \leq P \qquad \text{0-3}$$

$s_{i,k}$ is the binary charging variable for i_{th} EV connected to k-th SA. $L_{i,k}$ is the rated power of the EV. Objective function J is the aggregated convenience of all EV users, whereas $J_{i,k}$ is the convenience factor for individual EV per unit of power. So $J_{i,k}L_{i,k}$ is defined as the convenience of i-th EV. P_k given in 0-2 is the power limit for individual SA, whereas P indicated in 0-3 is the total power limit of the grid or system.

A User's convenience $J_{i,k}$ is calculated based on the desired and current SOC level of the EV, current and plug off time, and rated power value as shown in 0 4.

$$J_{i,k} = \frac{SOC_{i,k}^{desired} - SOC_{i,k}^{current}}{L_{i,k} \max(1, t_{i,k}^{plug\ off} - t^{current})} \qquad \text{0-4}$$

The convenience value indicates that the EV must reach to desired SOC level until plug off time.

The pictorial presentation of steps for distributed charging strategy is shown in Figure 69.

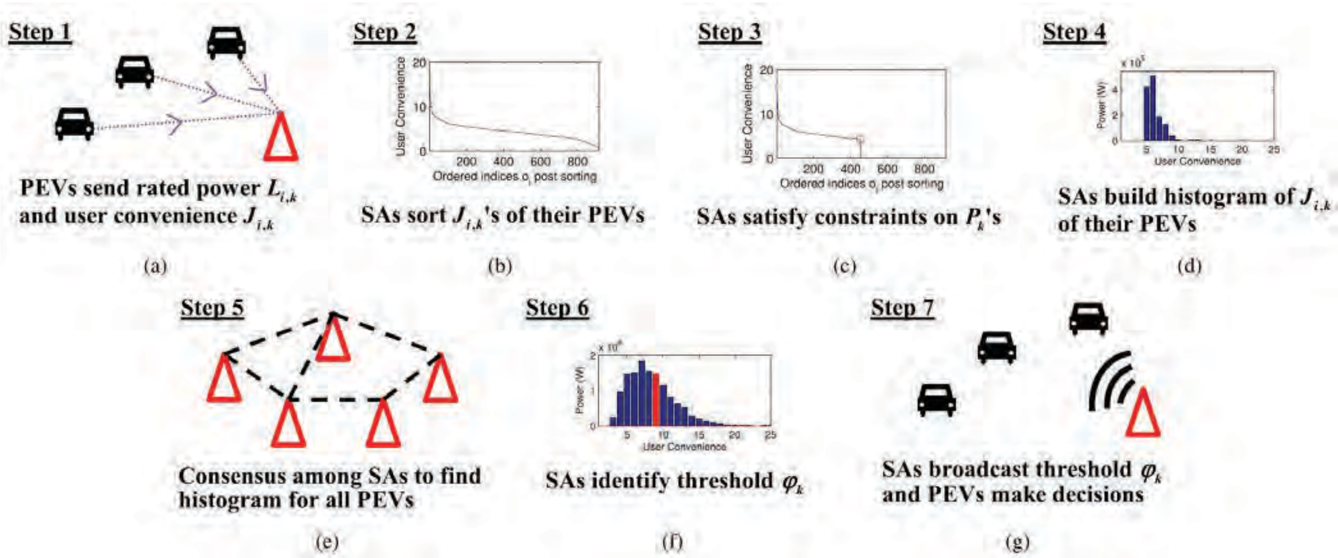


Figure 69: Stepwise pictorial representation of proposed method (Malhotra et al., 2017)

Step 1: All EVs connected to respective SA send rated power and charging requests in terms of the convenience factor.

Step 2: SA sort all EVs in decreasing order of their convenience factor. "Sort" is defined as the prioritization of EVs in decreasing order of convenience factor.

Step 3: SA satisfies the power constraint applicable to individual SA. Therefore, it does not cause system stress on any SA.

Step 4: Generate a histogram of convenience data provided by EVs.

Step 5: In this step, the consensus among all SA is taken, which satisfies the global power constraint. It also indicates that the system will not get overloaded.

Step 6: Individual SA decides on a threshold value of convenience factor. The EVs with convenience factor above the threshold value are allowed to charge

Step 7: Threshold value is communicated to allowed EVs from respective SA, and EV decides the charging.

The study (Malhotra et al., 2017) considers 10 SA and 400EV per SA. In Case 1, the plug-in and plug-out times of EVs are taken as 9-11 hrs and 15-17 hrs. The result of Case 1 is shown in Figure 70; it shows the target profile is closely tracked, and power constraints are also maintained while charging. In Case 2, 20,000 EVs are considered to have a heterogeneous plug-in and off time. Results for Case 2 is shown in Figure 71.

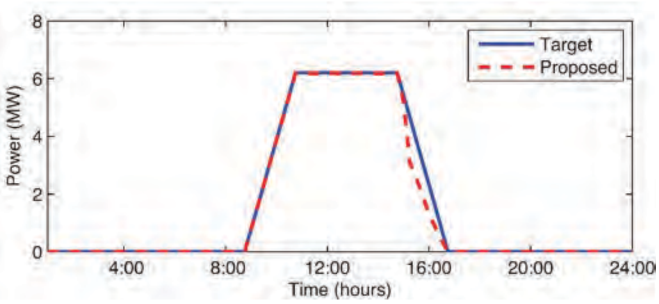


Figure 70: Power tracking 400 Evs with specific plugging time (Malhotra et al., 2017)

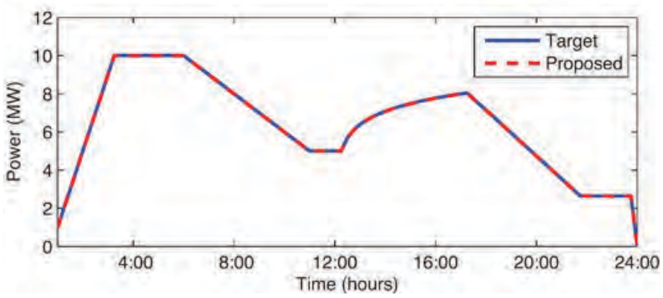


Figure 71: Power tracking of 20000 EVs with heterogenous plugging time (Malhotra et al., 2017)

Figure 72 indicates the track of the charging profile. Targeted and proposed curves overlap at all EV penetration levels that validates the objective of the strategy.

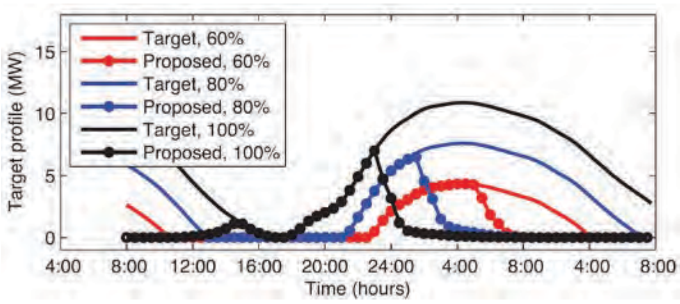


Figure 72: EV charging profile tracking (Malhotra et al., 2017)

The Hierarchical control is divided into a number of layers as per the nature of problem space and types of participants.

6.4 Hierarchical Control Based Strategy

The hierarchical control is divided into several layers as per the nature of problem space and types of participants. The architecture is divided into a central aggregator, subordinate layers of sub-aggregators, followed by EV owner layer (Nimalsiri et al., 2020). The control can again be sub-divided into several control strategies based on the decision-making authority, information signal flow, and required computation. It combines the benefit of centralized and decentralized strategies of directly controlling the charging and transferring the computational requirement for decision-making to the subordinate layer. Each layer of the architecture takes its own decision for achieving the desired objective without disturbing the other entities' objective.

The hierarchical control architecture is classified into four types based on the decision signal flow below.

6.4.1 HIERARCHICAL CENTRALIZED CONTROL

The control architecture shown in Figure 73 is hierarchical, where the decisions are taken in a centralized manner. The decision is taken at the central aggregator level and passed on to the sub-aggregators. Sub-aggregator optimally fixes the charging schedule for the EVs.

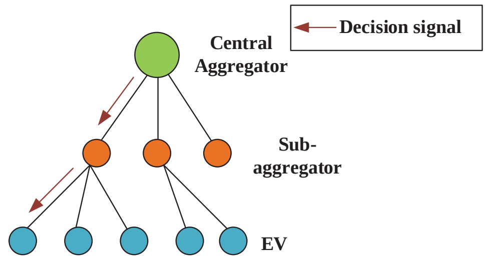


Figure 73: Hierarchical centralised control

This control inherits the characteristics of centralized control and hierarchical control. High bandwidth communication viz, Ethernet is recommended in this control architecture to mitigate the lag in the charging decision signal.

Advantage

1. It considers the global network constraints.
2. It guarantees the optimal solution.

Disadvantage

1. It is prone to halt the charging operation of the respective section if a fault occurs at the central or sub aggregator level.

6.4.2 HIERARCHICAL HYBRID CONTROL STRATEGY

It can again be classified into different types based on the decision signal flow. The first type, shown in Figure 74, has a hierarchical architecture and centralized decision-making at the central aggregators level and decentralized decision-making at the sub-aggregator and EVs level. In this control strategy, the central aggregator takes the charging decision considering network constraints and pass on to sub aggregators. Sub-aggregator has the information of the energy that it can deliver. At this stage, the sub-aggregator cannot dispatch the power according to availability because of decentralized decisions taken by the EVs. So, the sub-aggregator's role is to limit the requested charging energy within the allotted value, and failure of this will lead to the sub-aggregator getting penalized. To maintain the allowable energy limits, the sub-aggregator alters the electricity prices to influence the charging behaviour of the customers.

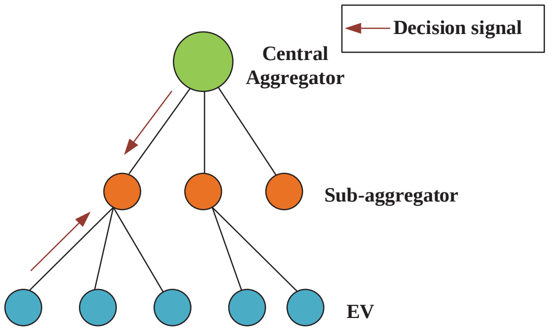


Figure 74: Hierarchical hybrid charging decision

Advantage

1. EV owners have the option of plug and charge, which motivates them to participate in smart
2. It ensures the network constraints are within limits by taking a centralized decision at the central aggregator level.

Disadvantage

1. Sub aggregator does not have direct control over the EV charging

The second type under this hierarchical hybrid control strategy is shown in Figure 75. In this type, decentralized decision-making occurs at the aggregators level, and the sub aggregator and EVs take the centralized decision. The energy requested is optimally scheduled by the sub aggregator considering the regional network constraints. The aggregated energy is then communicated to the central aggregator.

At this stage, the central aggregator tries to maintain the aggregated energy requested from each sub aggregator within systems limits by increasing the electricity prices.

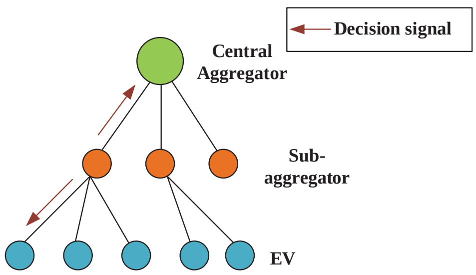


Figure 75: Hierarchical centralised charging decision

Advantage

1. It ensures the local optimal solution due to the centralized decision-making ability of sub-aggregator
2. Regional network constraints are directly controlled and maintained within limits

Disadvantage

1. It does not ensure the global network parameters are within the limit.

6.4.3 HIERARCHICAL DECENTRALIZED CONTROL

In this hierarchical control architecture, the decisions are taken in a decentralized manner, as shown in Figure 76. It allows decision-making at the EV level and passing of it to the sub aggregators. Sub-aggregator again gives the aggregated decision signal in terms of required charging power to the central aggregator.

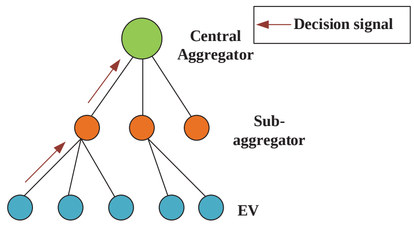


Figure 76: **Hierarchical decentralised control**

It inherits the characteristics of decentralized control and hierarchical control. Low-bandwidth communication is recommended in this control architecture.

Advantage

1. It is not prone to the stoppage of charging operation of the system if a fault occurs at the central or sub aggregator level.
2. It guarantees the optimal solution.

Disadvantage

1. The decision signal does not consider the global network constraint directly. It does not guarantee the optimal solution.

In a hierarchical decentralized coordination method, the decision is taken at the EV owner level and communicated to the upper level.

6.4.3.1 Hierarchical Decentralized Charging Coordination Method

As mentioned in the above section, a hierarchical charging strategy can be categorized based on the nature of decision-making (centralized, decentralized). In a hierarchical decentralized coordination method, the decision is taken at the EV owner level and communicated to the upper level. At the second level, based on the decision-making ability, the strategy is divided into two categories. When the decision is taken by the central aggregator and communicated to the sub aggregator, the strategy combines the benefit of both centralized and decentralized approaches within the hierarchical strategy. When the sub-aggregator communicates the charging decision to the central aggregator, the strategy is fully decentralized, and the charging is coordinated based on the hierarchical decentralized method (Zou et al., 2017).

Figure 73 to Figure 76 in this section shows different hierarchical strategies. The hierarchical decentralized charging coordination can be understood further with the below given illustrative example:

- Consider a network structure shown in Figure 77, which has a central aggregator at the topmost hierarchical layer.
- A1 and A2 are the sub aggregators at the second layer, with one hundred and twenty EV owners equally distributed between the two sub aggregators. The sub-aggregator's objective is to make a profit.
- At time-stamp t_0, a total of 50 EVs distributed equally between A1 and A2 are connected to the charging stations.
- 40 out of the 50 EVs are considered to be charging at , which included 20 EVs charging at their maximum charging rate.
- In this case, the central aggregator's objective is to maintain the delivered charging power within the capability of the system limits.
- At time t_1, for each sub aggregator, 10 additional EVs are connected for charging (now each sub aggregator has 30 EVs charging).
- An increase in energy requests (due to an additional 20 EVs) is communicated to the central aggregator by A1 and A2.

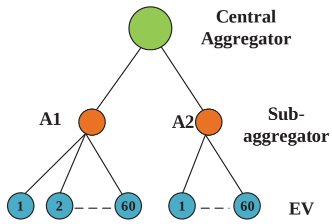


Figure 77: Example of decentralised hierarchical control structure

At time t_1, the central aggregator increases the per-unit charging electricity price by 'ΔC' value so that the system remains within the allowed limits for the next time slot t_2.

At t_2, 10 more EVs are connected for charging under each of the sub aggregators. The additional power demand due to the newly added 20 EVs drives the grid to its power flow limits. To ensure the system limits are not breached, the central aggregator aggressively increases the per-unit electricity prices by '2ΔC' to influence the charging behaviour of EV owners in the upcoming slots.

In each time slot, A1 and A2 increase their per unit electricity prices by ΔC1 and ΔC2.

This illustrative example describes the working procedure of a hierarchical decentralized coordination strategy. The hierarchical decentralized control strategy is primarily adopted to maximize profit, RE utilization and minimize power losses in the distribution system.

In this strategy, only the EV owner is involved in maintaining local parameters and EV charging decision. Local control only considers the local parameters, local constraints, and pricing signal for taking charging decision

6.5 Local Control Based Strategy

In this strategy, only the EV owner is involved in maintaining local parameters and EV charging decisions. Local control only considers the local parameters, constraints, and pricing signals for making charging decisions (Kevin Mets et al., 2010). This control only deals with the limited local constraints and linear single objective function, so the computation power required is significantly less than other smart charging control strategies. The decision signal is found at the local control, so communication (except the price information) is not required in this type of control. This control strategy is mainly applicable to private charging stations and especially home charging points. Different advanced local controllers are proposed in the literature that effectively handles multiple objectives at the local level.

Advantage

1. Simple and less expensive to implement.
2. Lowest computational efforts required as compared to other smart charging control strategies.
3. The best choice for home charging is a time-of-use tariff structure.

Disadvantage

1. It is unable to consider and maintain network constraints.
2. It does not reach the global optimal solution.

6.5.1 VEHICLE-DIRECTED SMART CHARGING STRATEGIES TO MITIGATE THE EFFECT OF LONG-RANGE EV CHARGING ON DISTRIBUTION TRANSFORMER AGING

The study in (Mobarak and Bauman, 2019) proposed a local strategy of vehicle-directed smart charging that individual EVs can use to charge more intelligently and thus lessen grid impact. Increased charging burden on the distribution transformer increases the transformer's ageing rate. Centralized and decentralized strategies can handle the accelerated transformer ageing issue by directly optimizing the network's and transformer's constraint parameters and dynamic electricity price, respectively. In both the methods, communication and computational infrastructure are required. Apart from these methods, the charge right-away is another simple charging strategy; however, that results in a high peak load and adds to the electrical burden on the distribution transformer. To eliminate increased peak load and burden on distribution transformer, the user requires a control mechanism that adds to the overall cost and intelligently handles this issue.

The problem statement addressed in the study is to develop a random-in-window (RIW) strategy that allows random charging start times within a specific time window after the residential peak load.

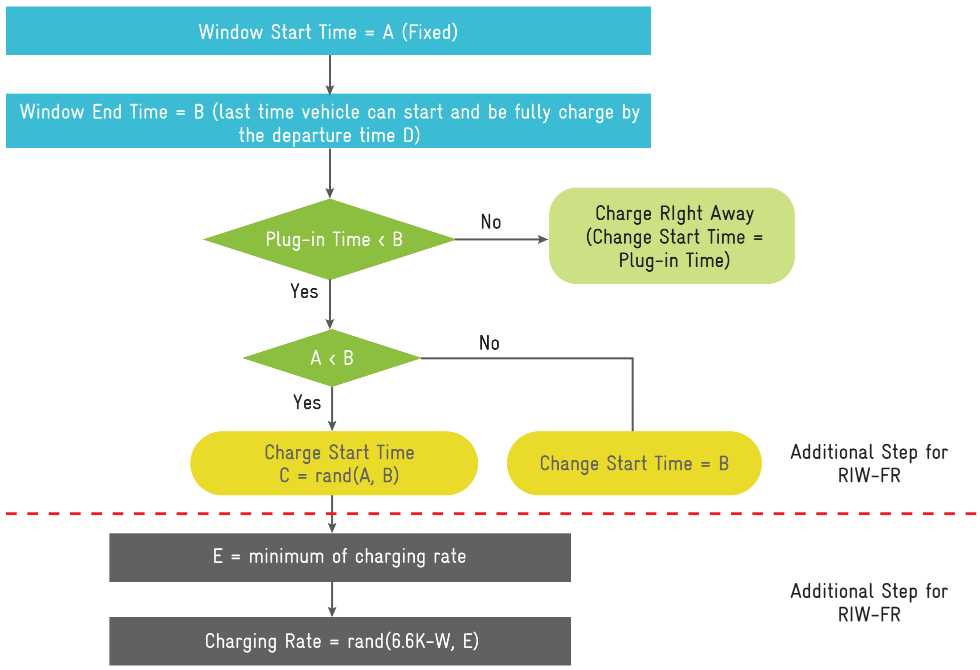


Figure 78: **Proposed RIW algorithm with FR and VR variants (Mobarak and Bauman, 2019)**

The proposed strategy uses a random charging strategy in a specific time window. Two variants of this random in window strategy, viz, fixed and variable charging rate is introduced. The expected time window for random charging must start after the time of household peak load. Different charging strategies are considered in the paper to compare the results with other available charging strategies. Uncontrolled charging strategies, such as charge right-way and vehicle directed charging strategies, such as time-of-use, charge by departure, random charging with fixed charging rate, random charging with flexible charging rate and smart charging strategy, have been analyzed in the study (Mobarak and Bauman, 2019). Results from all these strategies are compared to choose the best strategy among previously available and proposed strategies.

The overall structure of the proposed strategy is shown in Figure 78, which requires two input time values. One input is value: the time after household peak, and the other is the departure time for the next day. As shown in Figure 78, the value of time after the household peak (A) is set into the strategy, ensuring the household and EV charging load peak should not overlap to further stress the grid.

In the next step, the user must define the departure time for the following day's initial travel. It is used in determining the end of the random time window (B). The end of the random time value ensures that if any vehicle is attached at the end of the random time window, it will also be charged fully for the next travel.

Random charging is not allowed after time B to ensure the requested charging level. In the next case, when plug-in time is less than B, the decision condition between A and B will be checked, as shown in Figure 78. Then the only vehicle will get sufficient time to choose the charging time randomly and be ready for next day travel. If the value of A is greater than B, it exhibits that the household peak ceases after the end of the random time window, and straightway charging starts at time B. The algorithm's adverse condition happens when a vehicle is connected outside the random time framework. In that case, charging will take place with right away charging. In this, vehicles will charge at a fixed charging rate of 6.6kW. Therefore, the strategy is called random in the window with a fixed charging rate (RIW-FR).

An extension of this strategy in terms of charging rate is addressed in the next strategy, known as RIW-variable charging rate (RIW-VR). According to the flowchart shown in Figure 78, at first, charging time is chosen randomly. The minimum charging rate required (E) is then determined to fully charge the EV for the first travel on the following day based on the available time difference between departure time and random charging time found in the previous step. The formula for finding E is given 0 1:

$$E = \frac{\text{Battery Enery Required}}{\eta_{obc} \text{ x } (\text{Maximum Charging Duration D } - \text{ C})} \quad \text{0-1}$$

η_obc: Efficiency of on-board charger

The proposed study is performed on 150 vehicles using the logged data of arrival, departure, and plug-in time. The results from the proposed strategy are compared with other strategies for 150 drivers and their logged data.

For studying the impact of variation in EV specification in terms of power, vehicles are differentiated as long-range (60kWh-battery) and short-range (20kWh-battery) vehicles.

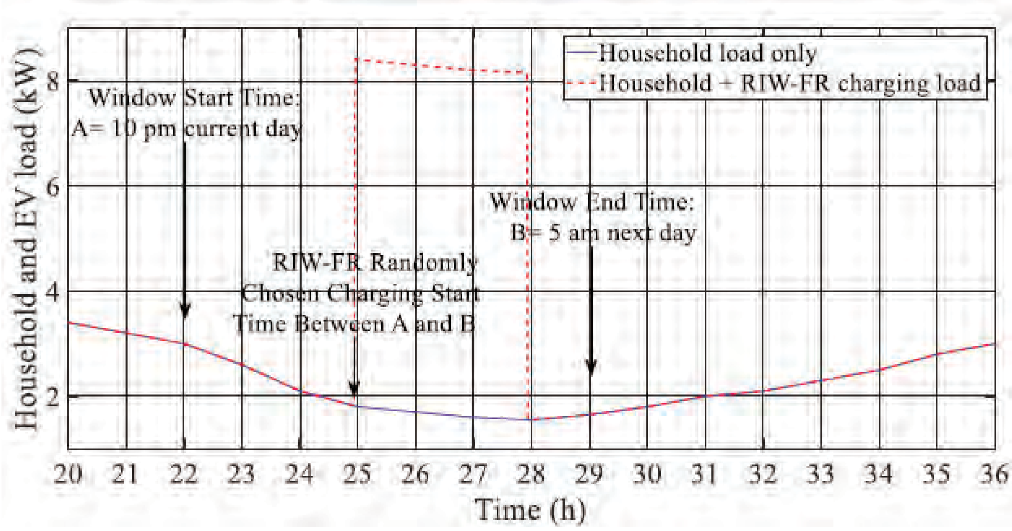


Figure 79: RIW charging profile of one EV load (Mobarak and Bauman, 2019)

Figure 79 shows that charging is started randomly between time window 10 p.m.-5 a.m. with a fixed charging rate of 6.6kW. It also indicates that charging after the household peak at 8 p.m. significantly reduces the stress on the system components.

Figure 80 depicts the household load profile without EV load and the entire household load with different types of EV. The resulting load curve for the RIW-FR method is shown in red. It shows that the off-peak time window is not fully utilized, and therefore, the load is not levelled throughout the off-peak time window. As shown in the green curve of Figure 80, this issue is addressed with a variable charging rate that tries to level the charging throughout the available charging window. From this, it is concluded that RIW-VR reduces more stress on the distribution transformer than RIW-FR.

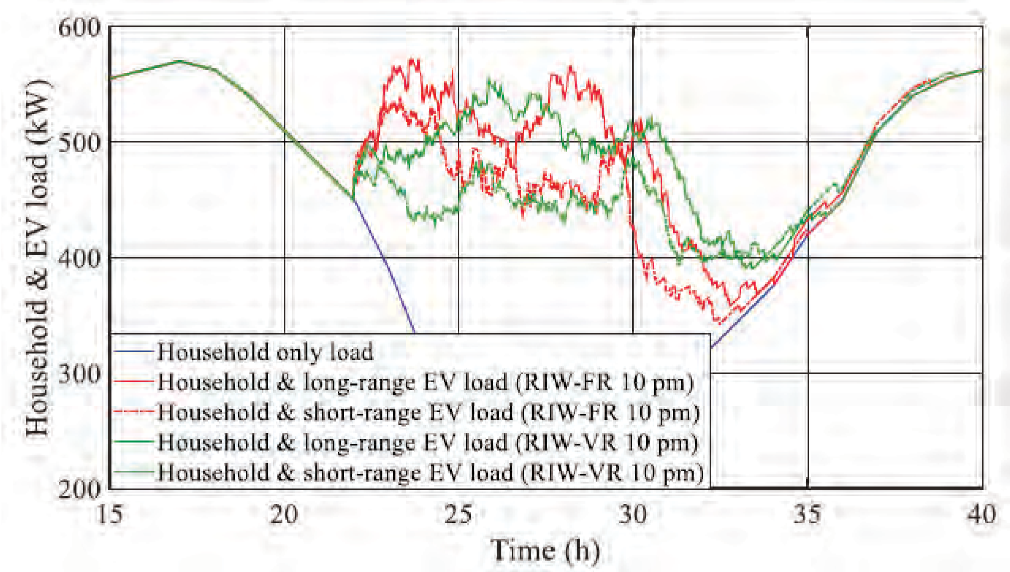


Figure 80: Long-range EV and short-range EV-simulated Monday load for 150 logged drivers (RIW-FR and RIW-VR charging strategies) (Mobarak and Bauman, 2019)

Transformer loading at different charging strategies is shown in Figure 81. It shows that the charge-by-departure strategy has a high transformer loading, whereas the proposed RIW-VR is charged with comparatively less transformer loading. RIW-VR charged in a distributive manner through an off-peak charging window which reduces the transformer loading significantly.

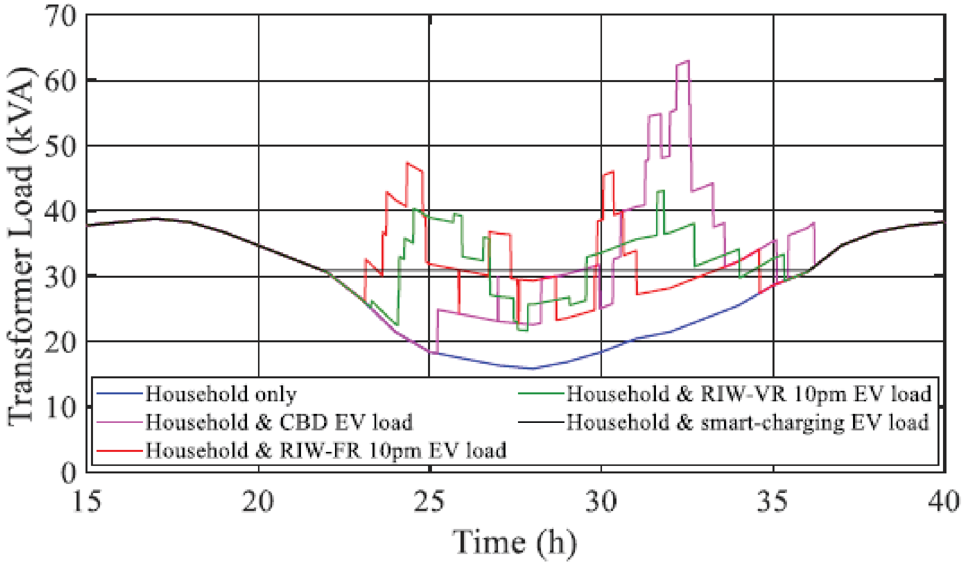


Figure 81: Charging load on transformer (Mobarak and Bauman, 2019)

Transformer ageing is indicated by the deterioration of insulation by temperature, moisture, and oxygen content in the transformer.

Transformer ageing is indicated by the deterioration of insulation by temperature, moisture, and oxygen content in the transformer. The hottest spot temperature () is directly related to insulation deterioration, so the ageing acceleration factor is defined as a function of the hottest spot temperature shown in 0-2.

$$F_{AA} = e^{\left(\frac{B}{383} - \frac{B}{\theta_H + 273}\right)} \quad \text{0-2}$$

To quantify how a typical transformer ages because of thermal profile, the equivalent ageing factor is defined as per 0 3:

$$F_{EQA} = \frac{\sum_{n=1}^{N} F_{AAn} \Delta t_n}{\sum_{n=1}^{N} \Delta t_n} \quad \text{0-3}$$

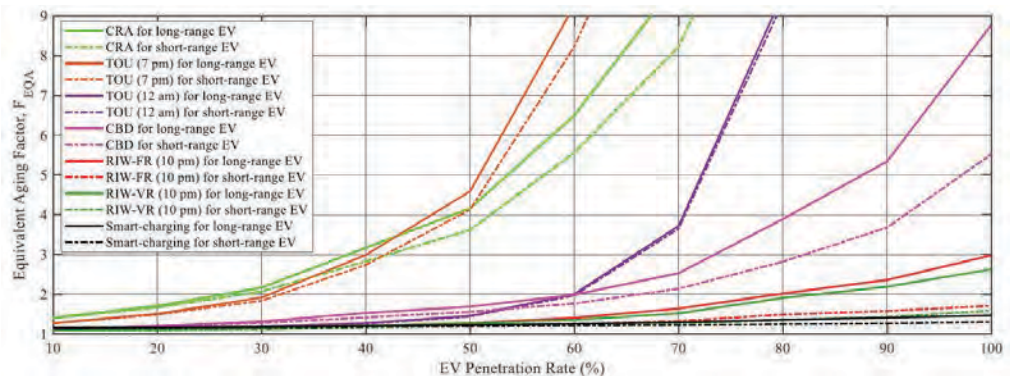
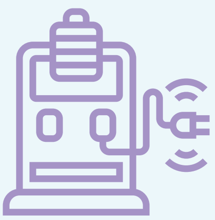


Figure 82: Transformer ageing factor at different smart charging options (Mobarak and Bauman, 2019)

Figure 82 shows the equivalent ageing factor (F_{EQA}) during different charging strategies. Results depict that the proposed RIW-VR strategy has the lowest transformer ageing factor among all the vehicle-directed strategies. Analysis shows that transformer ageing in RIW-VR strategy is identical to the smart charging at 50% EV penetration level (F_{EQA} = 1.28 and F_{EQA} = 1.23) respectively.

07
Objective-Based Strategies

The objective based strategies are applied to achieve predefined objectives based on the stakeholder's perspective. From the system operator's perspective, the fundamental objective is to maintain system stability by maintaining the network parameters within given limits. The centralized control strategy is considered the preferred choice to achieve system stability. The main objective of smart charging based on the EV owner's perspective is to minimize the charging cost. The aggregator is appointed to coordinate between the system operator and EV, whose primary role is to schedule the EV charging such that the objectives of both stakeholders are achieved. In addition to the prime role of coordinating and maintaining both objectives, the aggregator has one more personal objective: to earn profit from the scheduled charging. The decentralized charging control architecture best suits making a profit by an aggregator. A decentralized control strategy is considered to elaborate more on the mechanism of earning a profit by an aggregator. In this strategy, the aggregator has a role in maintaining the system constraint. The EV demand needs to be reduced to maintain system constraints within limits, But the aggregator does not directly control the EV charging in the decentralized architecture. For maintaining the constraint parameters, the aggregator increases the price of electricity for EV owners. The price difference between the electricity cost from DSO and electricity cost from the aggregator generates profit.



Some other objectives of smart charging are load flattening, increase in renewable energy utilization, and frequency regulation

Some other objectives of smart charging are load flattening, an increase in RE utilization, and frequency regulation. Various objectives of smart charging strategies based on different stakeholders' perspectives are given below.

1. **System operator's desired objectives**
   a. Maintain feeder line constrain within the limit (Ma et al., 2017)
   b. Valley filling (Liu et al., 2017) (Mao et al., 2019)
   c. Maximize utilization of renewable generation (Zhang et al., 2015) (Darab, 2018)
   d. Frequency regulation (Tan and Wang, 2016)
   e. Power regulation (Wu et al., n.d.)
   f. Reducing the system's constraint (Petit and Perez, 2013)
   g. Minimize energy loss and transformer operating cost (Eajal et al., 2015)
   h. Maintain voltage within the limit (power factor correction)] [(Xing et al., 2016) (power factor regulation)] (Eajal et al., 2015) (Sachan et al., 2020) (Sharma et al., 2019)
   i. Minimize system cost (Gonzalez Vaya and Andersson, 2012) (Wan et al., 2020)
   j. Load flattering and minimize peak load or load variance (Kevin Mets et al., 2010)

2. **Aggregator's desired objectives**
   a. To maximize green energy consumption (Petit and Perez, 2013)
   b. Electricity cost minimization (Jean-Michel Clairand et al., 2020)
   c. Maximize profit (Shakerighadi et al., 2018) (Sharma et al., 2019)
   d. Maximize solar utilization (Moradipari et al., 2020)

3. **EV owner's desired objective**
   a. Charging cost minimization (Zhang et al., 2015), (Xu et al., 2020), (He et al., 2016), (Moghaddam et al., 2018), (Abousleiman, 2015), (Clairand and Álvarez-Bel, 2018), (Sachan et al., 2020)
   b. User's satisfaction maximization (EV owner or user gets maximum satisfaction when the difference between the electricity price offered by the grid and the expected price of the owner is minimum) (Zhang et al., 2020)
   c. Reduce queue and waiting time (Abousleiman, 2015)
   d. Profit maximization (Shakerighadi et al., 2018)
   e. Maximize charging rate (Richardson et al., 2012)
   f. Minimize charging time, travelling time (Moghaddam et al., 2018)
   g. Find the nearest optimal charging station on the highway considering travelling distance, waiting time with limited charging infrastructure (del Razo and Jacobsen, 2016)

Centralized strategy is mainly applicable for load levelling, minimizing energy loss, minimizing system cost, and maximizing charging rate considering limits of network parameter.

Figure 83 lists objectives based on smart charging control strategies. Centralized strategy is mainly applicable for load levelling, minimizing energy loss, minimizing system cost, and maximizing charging rate considering limits of network parameters. Finding the optimal charging location considers available charging stations, the charging station's distance from EV's current location, queuing/waiting time, and fuel required to reach the charging station. The use of global constraints for finding optimal charging stations is achieved through centralized control strategy.

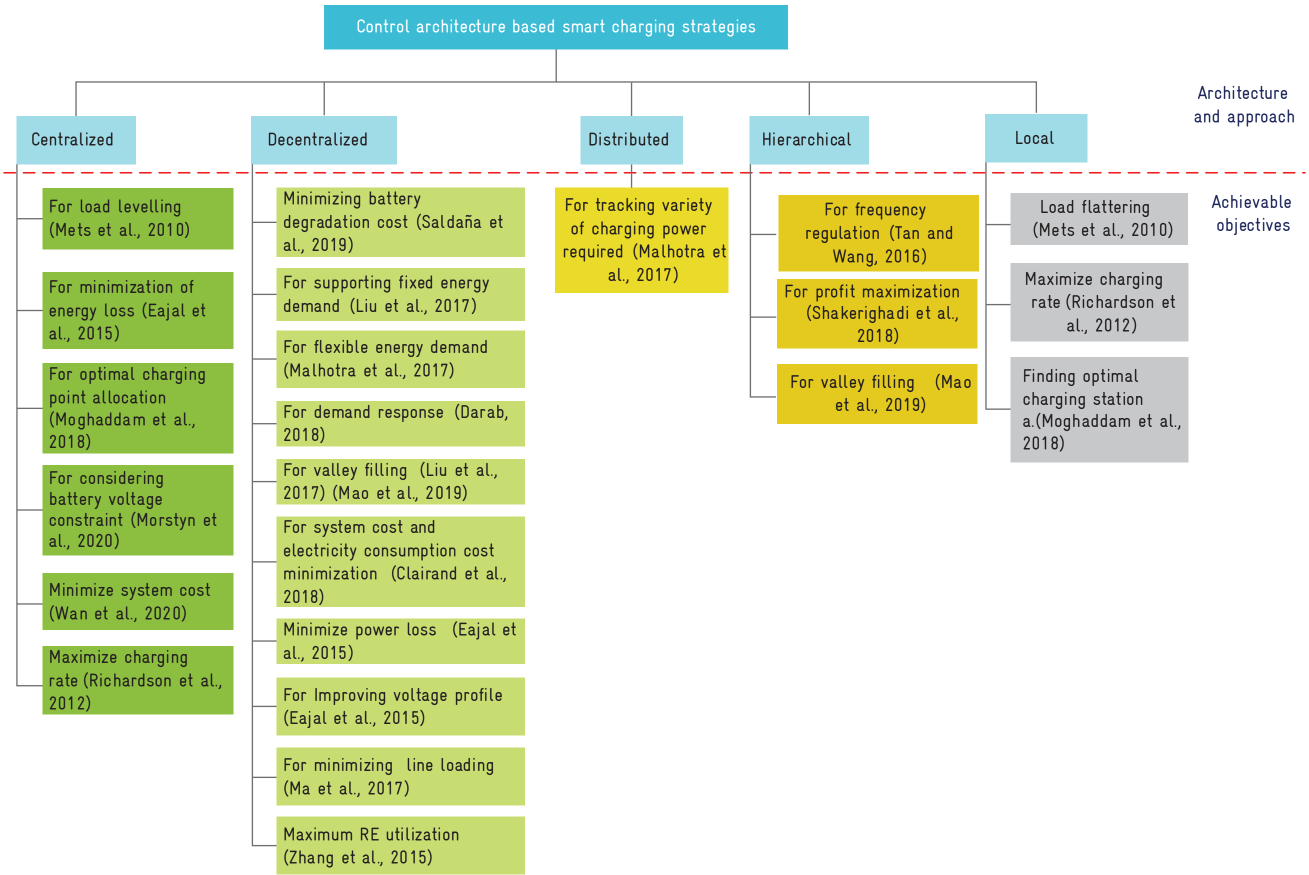


Figure 83: Smart charging strategies based on the control architecture

The decentralized control strategy is the favourable choice for the objectives directly related to the electricity cost.

The decentralized control strategy is the favourable choice for the objectives directly related to the electricity cost. The list of objectives that work based on decentralized control is shown in Figure 83.

As mentioned above in this section, earning profit is one of the main objectives of the aggregator. The aggregator can quickly achieve this objective in hierarchical control architectures as the players are free to achieve their own objective in each level irrespective of the other players' objectives. So, the profit maximization of aggregators is aligned with the hierarchical control strategy.

Figure 83 summarizes that the objectives depending on global constraints are achieved with centralized, decentralized/distributed or hierarchical strategies (Amjad et al., 2018). The objectives depending on local constraints, are realized with local strategy.

7.1 EV Charging Coordination Under Feeder Capacity Constraints

In EV charging coordination strategies, the feeder's maximum allowed capability is the constraint parameter while performing EV charging. Considering feeder capability for charging optimization is an important parameter because the feeder overloading can potentially result in feeder tripping, leading to congestion of other lines. Because of this reason, EV charging is coordinated under consideration of the maximum feeder capacity. Feeder capacity constraints can be considered in two different ways while performing an optimization. The first option is by considering the thermal rating of the line. The second method of realizing the feeder constraint is by considering the amount of prespecified power flowing through the feeder, which can be calculated using load flow analysis or optimal load flow studies.

Applying feeder capacity constraint is simple in a centralized method as all decisions are taken centrally by performing load flow analysis, and EV owners are not involved in charging decisions. The centralized mechanism is not very popular amongst customers as it does not facilitate the direct plug-and-charge mechanism. This reduces the customer's degree of satisfaction, and people are less interested in such charging strategies.

Contrary to this, applying feeder constraint in a decentralized strategy is difficult because the EV owner takes the EV charging decision based on electricity price without considering any network constraints. Dynamic price variation by an aggregator cannot guarantee the optimal solution to maintain the feeder's capacity constraint. The aggregator decides the variation in price signal by taking the information of load flow and power requests from the customers. However, this decentralized control strategy alone is not sufficient to maintain feeder capacity constraints, as a failure in maintaining capacity constraints from this approach may lead to system instability. So, another local control is also used in addition to decentralized control for arresting capacity constraints.

7.2 Coordinated EV Charging and Distributed Generation Control in the Distribution Network

The presence of EVs and distributed generators are complementary to each other. EV adoption will be successful only if there is enough energy available from renewable generators. On the other side, more distributed generators can be integrated into the system if a mechanism is available to neutralise the uncertainty in distributed generations. EVs are a well-suited and economical option for increasing RE penetration in the grid. This requires common and balanced coordination between the specific objectives of EV charging and distributed generation. High penetration of distributed generators may lead to a rise of the system voltage due to reverse power flow. On the other hand, high penetration of EV may lead to a drop in the system voltage. Using balanced coordination of EV charging and distributed generation, the system voltage stability is supported, and violations of limits are reduced.

Using balanced coordination of EV charging and distributed generation, the system voltage stability is supported, and violations of limits are reduced.

Another encouraging parameter from the EV owner's point of view is the reduced electricity cost when powered with RE generation. Thus, maximum energy usage from RE resources is necessary to make EVs a more sustainable alternative for gasoline-powered transportation. The points highlighted above encourages effective coordination between EV charging load and distributed generation. Coordination between EV charging and distributed generation can be performed using centralised, decentralised, hierarchical, distributed, and local strategy. The objective of all the strategies is to maximize the utilisation of RE generation. This objective is mathematically modelled to minimise the cost of electricity as RE is available at a relatively lower price. The detailed working of the strategies for coordination of EV charging and distributed generation is given below.

In centralised strategies, direct coordination happens by taking a centralised decision on the charging power. The objective is modelled as cost minimisation with the required grid safety constraints. The aggregator schedules maximum possible charging from RE each time, reducing the cost and increasing the customers' satisfaction in both ways, viz, by minimising charging cost and maximum charging at the daytime (especially in solar PV generation). This objective is mainly adopted at the workplace charging station and public charging stations.

The distributed strategy provides a global optimal solution by scheduling the available renewable for EV charging at other location.

In decentralised strategies, the aggregator has information on the expected forecasted value of renewable generation. Using the knowledge of forecasted RE generation, the aggregator lowers the electricity prices during renewable energy generation rich hours. The coordination process between EV charging and RE generation is implemented by finding the effective price of electricity coming from conventional stations and RE generators and trying to minimise the total cost of EV charging (Clairand et al., 2017b). On the same strategy, distributed control communicates within aggregators and attempts to accommodate all the other aggregators' RE. This pushes the system towards an optimal solution for maximum RE utilisation and minimizing the electricity cost. The distributed strategy provides a global optimal solution by scheduling the available renewable for EV charging at other locations.

Hierarchical strategy for coordinating EV and RE generation works in a combination of centralised and decentralised strategies. So, it can provide dual benefits of both the strategy in terms of direct control and customer satisfaction. Another highly adopted strategy for coordination between EV charging and RE generation is the local strategy. Local controllers optimally schedule the EV charging based on the availability of RE generation and cost minimisation. One more objective function is to implement the minimisation using energy from the grid and to utilise the maximum possible local RE generation. This strategy is mainly adopted among the population in the household and captive charging conditions.


DRIVE ON SUNSHINE
america

08

Smart Charging Strategies Based on Optimization Algorithms

From the computational perspective, smart charging is an optimal solution of EV schedule considering various constraining parameters, which can be found out using several different established methods. Optimization methods, data-driven method, AI and ML-based methods, fuzzy method, model predictive control method are some approaches for finding optimal EV schedules while maintaining network constraints (Amjad et al., 2018). Within the scope of this report, the focus will be on optimization methods and game theory-based methods for smart charging. These methods need a large quantum of training data which, however, is available in limited quantity.

This data is sensitive to the location and its specific characteristics from where it is collected. The same training data will not help train any smart charging AI or ML-based model in some other parts of the world. Considering this limitation of AI and ML-based methods, the details of these approaches are not covered in detail. Figure 84 shows the optimization algorithms used for performing smart charging.

Optimization methods, data-driven method, AI and ML-based methods, fuzzy method, model predictive control method are some of the approaches for finding optimal EV schedules while maintaining network constraints

Optimisation algorithms work for specific constraints and optimization domains. Mostly linear optimisation algorithms are used to perform cost minimization considering basic network constraints such as operators maximum allowed power.

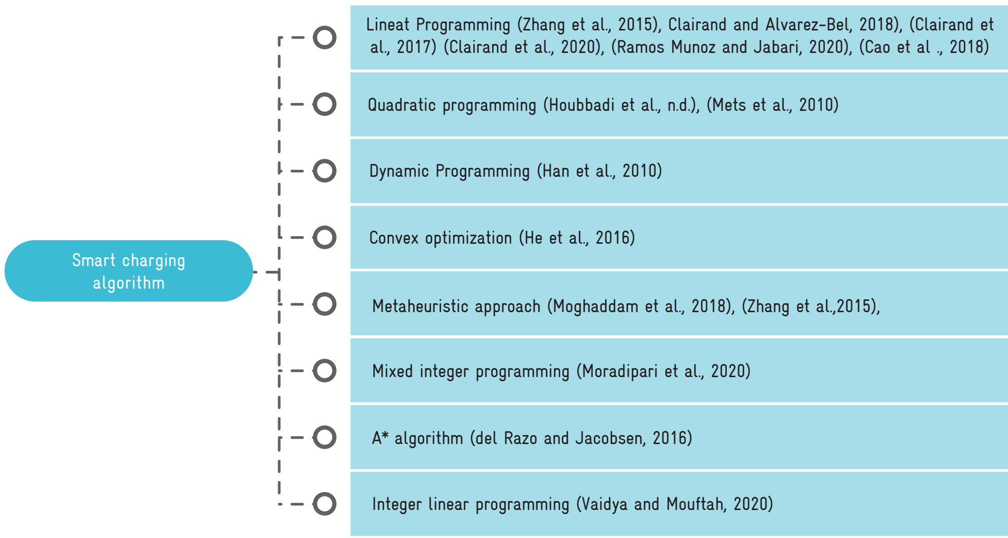


Figure 84: Optimization algorithms for smart charging

Mixed-integer linear programming (MILP) is another popular optimizing algorithm in the smart charging domain, in which some of the variables are constrained to be integers. This method offers a strong computation capability necessary for the smart charging problem. Metaheuristic methods are also applicable for solving smart charging optimization problems. The search for the optimal solution is initiated in a search space with a dimension equal to the number of EVs in the system. Particle swarm optimization, ant colony optimization, and genetic algorithm are some of the metaheuristic optimization algorithms used in literature for smart charging. For other optimization algorithms as MILP, convex programming, dynamic programming is used to handle the additional constraints and solves different objectives.

09

Artificial Intelligence/ Machine Learning-Based Charging Approach

In chapter 6 and chapter 8, EV charging and coordination are discussed based on control architecture and optimisation approach. Data-driven AI and ML-based solutions are another approach for scheduling and coordinating EV charging (Frendo et al., 2020). In this approach, models are built and trained to understand the behaviour and characteristic of participating entities with many scenarios with different participating entities. This training is performed using standard training sets or different scenarios generated in simulations. Based on the available training sets, the AI/ML-based strategy is categorised into supervised and unsupervised learning (Shahriar et al., 2020). There is limited labelled standard training data available. The available training data is also sensitive to geographical location, so the available training data is also not used to train the data for the model at any other geographically different place. Due to the scarcity of available training data unsupervised learning algorithm is the populator choice. In an unsupervised algorithm, unlabelled training data is used, and the results differentiate the EV charging behaviours from given input parameters. K-means clustering, Gaussian mixture model, Kernel density estimator are some of the methods used in literature for unsupervised learning. Linear regression model, decision tree, random forest, space vector machine are some supervised methods. When the input information is provided to the model, it predicts the change in the smart charging profile and provides the optimal charging power dispatch to EVs requesting it.

ML predictive models also depend on the quality of the data set used for training. The standard training data is taken from available EV charging projects for residential and non-residential charging. Based on the response variable to be predicted, the problem is called a regression problem with a continuous predicted response variable. If the response variable is categorical, then the problem is classified as a categorical problem. Deep learning and reinforcement learning are more advanced ML algorithms that learn from mistakes and errors.

Due to the scarcity of available training data unsupervised learning algorithm is the populator choice.

10

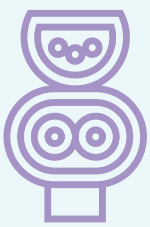
Price Based Coordination Methods

Electricity price is categorized into fixed price and dynamic price based on time of use and energy demand. However, the fixed price is generally not effective for pricing. Hence, dynamic prices are adapted for pricing the EV based on coordination methods. The pricing schemes for dynamic electricity prices are divided as Real-time price (RTP), Time of use (TOU), Critical peak price (CPP), and Peak time rebate (PTR) (Zhang et al., 2020). Each of these pricing strategies is applied to influence the charging behaviour of customers indirectly. Details of EV coordination and price-based methods are provided below.

10.1 Real-Time Pricing

The electricity cost is updated every time step as per the network's requirement. If a flat price is applied for EV charging, that might create an uncertain peak at any time of the day as per customers charging behaviour. Updated prices as per various parameters are required in the EV charging system to avoid this undesirable peak load condition. Charging requests or charging demand, availability of energy, maximum allowable power limits, and available RE supply are the major reasons behind price variation. Some other constraints like feeder capacity line loading and transformer burden also indirectly affect the electricity prices. This real-time price variation allows the charging cost minimization objective to be performed in a real charging scenario.

Decentralized and distributed control strategies are majorly adopting real-time pricing mechanisms. In a decentralised real-time price coordination approach, the aggregator updates the price signal for the next time slot to control the EV charging as per the grid's safety. Centralized strategy can use real-time pricing, but in this case, the aggregator is not varying the price. Here, the aggregator is following the real-time prices from the pricing market. In practice, a centralized strategy does not require real-time pricing as the control parameter over EV charging. So, in many centralized case studies, the time-of-use time of tariff structure is generally used. Real-time pricing signal has one more important objective of demand response, which directly eliminates ancillary support requirement (Chen et al., 2017).



Real-time pricing signal has one more important objective of demand response, which directly eliminates ancillary support requirement

In (Chen et al., 2017), automatic demand response (ADR) is implemented with real-time pricing. The author used two models, namely, the Dynamic Price Vector Formation Model (DPVFM) and the Dynamic Feasible Energy Demand Region (DFEDR) for PV attached charging station for ADR. The comparative result for cost and voltage profile for proposed ADR using fuzzy C means and K means algorithm is highlighted in the paper.

10.2 Time of Use Tariff

The time-of-use (TOU) tariff is defined as the fixed price allotted to time slots. These prices are published on an actual day of operation so that the customer can schedule the operation of appliances to reduce the electricity cost by shifting the flexible loads to a low price period. TOU tariff can perform smart charging without actually controlling the charging rates. It requires significantly less additional infrastructure and can give better results in terms of electricity cost. So, this tariff structure is globally used in many projects and locations. TOU indirectly facilitates increased RE utilization, reduced transformer loading and peak load but does not ensure an optimal solution and grid stability. It also allows load levelling or valley filling and cost minimization.

TOU tariff can perform smart charging without actually controlling the charging rates. It requires significantly less additional infrastructure and can give better results in terms of electricity cost.

TOU tariff is used in centralized charging where the aggregator considers this tariff to optimize the charging to reach the desired objective. TOU tariff is not applicable in decentralized and distributed strategies because the concept behind this strategy is based on dynamically varying prices as per the requirement. TOU tariff significantly reduces the charging cost compared to uncontrolled charging. It allows cost minimization and smart charging in an uncontrolled EV environment. It can be applied to largest possible EV fleet since it does not require any additional infrastructure, communication, and computational power.

Moving TOU using Gaussian-model based clustering technique is described in (Newsham and Bowker, 2010). In this study, Gaussian model-based clustering technique is used to find the TOU duration. In (Yin et al., 2015), the regional TOU pricing model is introduced, categorizing the urban area into four different zones: industrial, commercial, office, and residential. The comparative analysis of peak valley difference and charging cost is carried for TOU and regional TOU tariff.

10.3 Critical Peak Price

Critical peak pricing works under the same TOU principle; the difference is that it is applied for a period of high demand. It is not decided on historical data, and rather forecasted data is used to apply and publish quickly. The electricity price is very high in CPP compared to TOU, so it is more effective than TOU for peak load reduction (Newsham and Bowker, 2010). For applying CPP, days are categorized into critical days and non-critical days using various methods, such as particle swarm optimization (PSO) and ML-based clustering techniques.

10.4 Peak Time Rebate

In this tariff structure, the utility provides a rebate to the customer to limit consumption within a predefined limit (Dutta and Mitra, 2017). Customer views it as a gain. However, shifting load to off-peak time is considered a loss. The economic effectiveness of the scheme is dependent on the predefined critical baseline load as it requires development of precise baseline load (Newsham and Bowker, 2010).

This section has explained different types of strategies based on control architecture and major strategies in detail.

10.5 Dynamic Price-Based Coordination Methods

Electricity charging price is classified into two categories time-of-use price and dynamic price. Dynamic price-based coordination is applied in combination with centralized, decentralized/distributed, and hierarchical strategies. Dynamic electricity prices mainly influence cost minimization, maximum RE utilization, and ancillary services as charging costs are the important constraint. In this method, the optimal charging solution is determined at every time slot as per the dynamically varying prices (Xu et al., 2020).

In a price-based coordination strategy, the zonal and regional prices coordinate and influence the EV's charging behaviour. EV charging and time-of-charging are uncertain and random by nature, making it difficult for the operator to manage disordered charging requests. For tackling this issue of disordered charging, a price-based approach is used in the literature. In this price-based approach, the zonal price is calculated, which changes the customer's charging behaviour with the grid requirements, customer requirements, and the benefit of all the parties involved.

The regional information about the number of EVs and charging stations is collected and processed to calculate the charging demand on the charging station per EV. This value highlights the status of charging infrastructure available at the regional level. According to this value, the zonal prices are optimally determined considering the profit maximization principle. Considering this price at the zonal level, TOU tariffs are published, encouraging customer participation in smart charging. TOU tariff increases the customer's degree of satisfaction as it resembles a simple plug and charge mechanism. In the literature, the genetic algorithm has often been used to optimally find the zonal prices by considering all the constraints required for grid stability.

Dynamic electricity prices mainly influence cost minimization, maximum RE utilization, and ancillary services as charging cost are the important constraint.

As a result of the dynamic priced based strategy, the peak-to-valley ratio is reduced compared to the mechanism without optimal pricing. This strategy formulates a multi-objective optimization problem to find an optimal point from the perspective of EV owners and grid operators. This multi-objective problem aims to maximise users benefit, maximise revenue from the grid, and minimise load fluctuation. While performing this optimal TOU tariff scheme, it is necessary to restrict the value of TOU to maintain its affordability by the EV owners. For this reason, an upper and lower bound of a pricing value is fixed for each time slot. The price bounds are changing based on the time of the day as peak time, valley time, and flat load time. Another restriction on the TOU price is the difference between the average value of the TOU tariff in a day and the average prices at flat load and valley load time. This difference should be less than the predefined threshold value to make the optimal time of use tariff affordable for EV owners.

An optimal price-based strategy can also lead to an uncertain peak in the system in valley time because of very low cost, which is not desirable. Hence, a threshold value is predefined to eliminate this possibility of uncertain peak demand at valley time. The difference between flat and peak load times should be less than this threshold value to arrest the uncertainty with high charging at valley hours.

10.5.1 Decentralized Dynamic Pricing Mechanism for Demand Response

To maintain generation-demand balance, demand response from the EV charging load is the preferred choice of system operators because of the shiftable nature of EV charging load. Electricity price is the only influencing parameter in performing demand response in the decentralized strategy. This leads to the decentralized dynamic pricing mechanism for demand response (Chen et al., 2017). In this mechanism, the aggregator dynamically varies the electricity prices when a demand-generation mismatch is present in the system. This dynamic price variation indirectly forces EV owners to reduce the demand. This action of aggregator invisibly performs demand response from EV charging load in a decentralized framework.

In the demand response situation, some of the restrictions on the pricing signal variation are not applied to restrict the charging behaviour of the EVs aggressively. If these additional price constraints are not eliminated at the demand response time, it might not give the desired results in terms of demand response. As mentioned above, there are many restrictions on the value of the dynamic prices to make it affordable for the customer at normal operating conditions. These restrictions on dynamic price variations are the minimum and maximum price limits. The price difference between average prices that should be less than a threshold value is omitted in the demand response situation. In a decentralized strategy for demand response, the aggregator is free to set the prices in a grid safety situation; otherwise, it may lead to grid instability and grid collapse.

Detailed information on different strategies for smart charging, optimization approaches, and smart charging techniques available in the review papers format in literature are listed in Table 15.

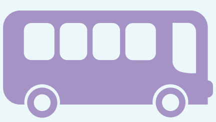
Table 15: List of reference papers in literature

Topics covered	Source
Optimization techniques and charging techniques and charging approaches, and optimization based on the objective function	(Amjad et al., 2018)
Provides the idea on EV for developing countries	(Rajper and Albrecht, 2020)
Provides optimal charging strategies unwder a dynamic pricing scheme	(Amin et al., 2020)
Described optimization algorithms for distributed control	(Nimalsiri et al., 2020)
Survey-based on optimization algorithmic perspective is presented	(Wang et al., 2016)
Interactive and intelligent smart charging is reviewed	(Chan et al., 2014)
Machine learning-based smart charging approach is detailed, focusing on unsupervised learning	(Shahriar et al., 2020)
Smart charging techniques for providing ancillary service, considering battery degradation cost, are provided in detail.	(Saldaña et al., 2019)
Promising practices of smart charging globally is given in details	(Hildermeier et al., 2019)
Smart charging strategy of electric vehicles in the presence of photovoltaic and grid power is given.	(Fachrizal et al., 2020)2020

11
Fleet Control Charging Strategy

Fleet control is applicable to public/private passenger buses, logistic vehicle fleets, and heavy-duty commercial fleets. Its control and coordination are motivated for specific objectives, such as maximizing the EV charging during off-time, maximizing the RE utilization, and finding optimal coordination between charging sessions and travelling trips. Figure 85 shows the different objectives of fleet control. The centralised strategy is majorly used for fleet control as it can schedule the fleet charging based on different objectives.

In addition to system operators' desired objectives mentioned above, it also helps achieve fleet operators' desired objectives of planned trips with minimum energy at the coordinated lowest possible time. From the fleet operator's perspective, the vehicle fleet should coordinate the charging such that it will not affect the travelling schedule of any vehicle in the fleet. Fleets are charged in a coordinated manner by allocating appropriate charging stations on the route or bus depot. Charging the fleet at off-service time necessitates the need for coordinated control to reduce the extra burden on peak load due to fleet charging of the heavy-duty vehicle. For long-distance travel or a routine travel charging allocation over the travelling route, charging points are also essential to cover long distances and reduce the load on a single charging station.



Fleet control is applicable to public/private passenger buses, logistic vehicle fleets, and heavy-duty commercial fleets

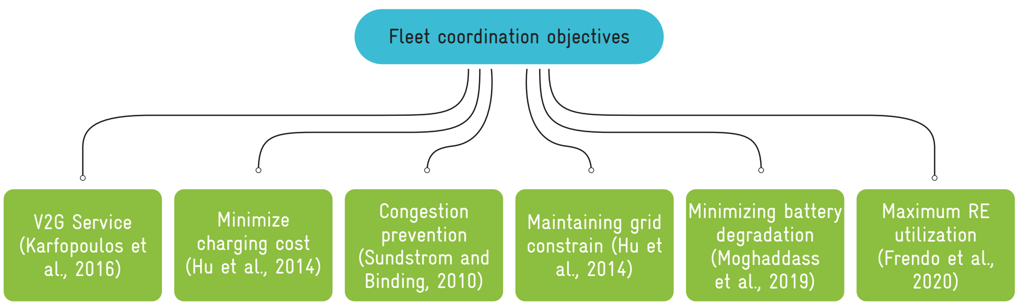


Figure 85: Objectives for fleet coordination

Local RE integration at a fleet operated charging station is the best solution for cost minimization and system's stress reduction. However, the strategy of integrating RE into the fleet operated charging station poses some issues in time coordination in between travelling time and RE availability. For example, suppose the charging station is energised from local solar PV. In that case, the RE generation will be available only in the daytime, but it is inconvenient for the fleet to charge during the day due to the travelling schedule.

This issue can be technically addressed by adding battery storage which will increase the charging station's capital cost. So, smart charging in a coordinated manner is the best way to manage fleet charging with RE utilisation.

Fleet coordination is performed using different optimisation methods as linear, quadratic programming, mixed-integer linear programming, etc. Some control approaches such as droop-based control and fuzzy control are also used for fleet coordination. In addition to optimisation and controller-based approach, it is also being coordinated using a data-driven and machine-learning-based approach. Objectives, approaches for implementation and methods for fleet control and coordination are shown in Figure 85 and Figure 86.

The strategies described above have different associated attributes related to computation, communication, and cost. A comparison of different charging strategies based on various attributes is shown in Table 15, which shows that centralised strategy requires the highest cost investment, high bandwidth, and computation capabilities but low in flexibility and scalability. Table 16 summarises fleet coordination based on implementation methods mentioning objective functions, constraint parameters, and applications.

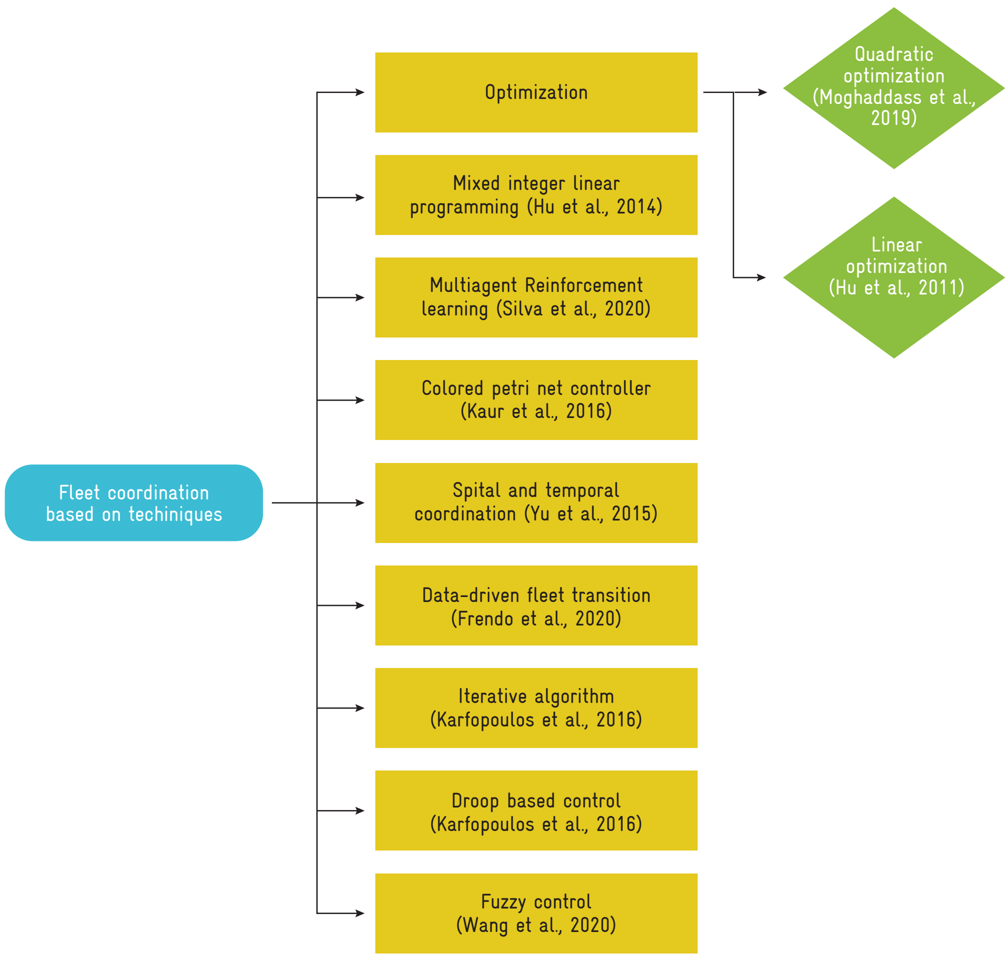


Figure 86: Methods for fleet coordination

Table 16: Comparision of different charging strategy

Higher | Medium | Low/less

Control	Centralized	Decentralized/ Distributed	Hierarchical	Local
Implementation efforts required	Higher	Medium	Higher	Low/less
Communication required	Higher	Low/less	Medium	Low/less
Adaptable with large number of EV's	Low/less	Medium	Medium	Higher
Cost required	Higher	Medium	Medium	Low/less
Computational burden	Higher	Medium	Medium	Low/less

Table 17: Summary of fleet coordination based on implementation methods

Algorithm	Objective	Parameters	Application in EV charging	Reference
Mixed-integer multi objective optimisation	**Power system objective** 1. Minimize power system cost 2. Minimize load variation **EV owner's objective** 1. EV owner's charging cost 2. Minimize difference between desired and effective SOC 5. Minimise travelling distance to charging station 6. Minimise waiting time at charging station	**Power system's parameters** 1. Capacity limit of the system operator 2. Cost of electricity production **EV owner's parameters** 1. Minimum and maximum required SOC 2. Power consumption of EV 3. Maximum charging rate of battery **Charger and charging station's parameters** 1. Maximum charging rate of the charger 2. Selling electricity price	1. Minimise charging cost 2. Minimise power system losses 3. Maximize benefit from providing different regulation services	(Moghaddass et al., 2019)
Linear programming	Minimise the charging cost of the EV fleet	1. Predicted electricity price 2. Predicted driving pattern	Minimize charging cost	(Hu et al., 2011)
Projected sub-gradient method	Minimize cost function (Congestion minimisation)	1. Energy requirement of fleet 2. Predicted price signal	1. Maintain feeder capacity constraint 2. Congestion minimisation	(Hu et al., 2014)

Algorithm	Objective	Parameters	Application in EV charging	Reference
Colored Petri Net	Provide frequency support	1. Battery capacity 2. Voltage battery	Provide ancillary services	(Kaur et al., 2016)
Spatial and temporal coordination	Minimise load variance	1. Charging load power	1. Minimize the charging cost 2. Maximize user's degree of satisfaction	(Yu et al., 2015)
Adaptive droop control	Frequency support	1. Regulated dispatch request signal 2. SOC 3. Battery current	1. Maintain voltage within limits	(Karfopoulos et al., 2016)

12

Charging Station Coordination

Suitable coordination of charging stations within the network is necessary for optimal power-sharing within the charging station after optimal charging power allocation based on the grid's available power capacity and EV's energy requests at the network level. Optimal charging power coordination within charging station is determined by considering various objectives, such as profit maximization of charging station, delivery of requested power within parking time slots and avoidance of overloading of the station infrastructure. Charging station coordination requires a priority list of EV charging based on customer preference of smart charging, parking time and the difference between parking time and time required for charging with the maximum charging capacity. This prioritization helps coordinate charging stations as per the charging station operator's and EV owner's preferences. Optimal charging power allocation and vehicle-to-charging station coordination are combined to perform smart charging for an EV. The necessity and importance of charging point coordination are discussed using two example cases as described below.

Case1: In the G2V mode of operation, the aggregator will optimally allot charging power at every slot. After receiving the charging power signal, the charging station operator's responsibility is to coordinate the allocated power within available charging points. This optimal charging point allocation considers the objective of maximum revenue generation, satisfying customers' requirements based on the rating of EVSE and parking time allotted to the EVSE.

Case2: In V2G operation, the aggregator will generate a quantum of discharging power for an individual charging station. After receiving the allotted signal, the station operator's responsibility is to coordinate the available EVs for discharging at that instant. This optimal discharging power allocation is decided based on the SOC level, battery specification, and the vehicle's remaining parking time.

> Charging station coordination requires a priority list of EV charging based on customer preference of smart charging, parking time and the difference between parking time and time required for charging with the maximum charging capacity.

As reported in the literature, the studies on charging points coordination majorly use multilevel optimisation, where the first level is the optimal allocation of charging power to individual charging stations. The second level is optimal charging power allocation to individual charging points or EVSE within the charging station. These two

Charging station coordination requires a priority list of EV charging based on customer preference of smart charging, parking time and the difference between parking time and time required for charging with the maximum charging capacity.

operation levels are cyclic processes for performing smart charging of EV. The game theory approach applies to such multilevel optimisation since it allows each level to optimise the objective function of their specific interest. It resembles the actual performance of participants in EV charging space such that each EV has their own charging behaviour, and each EV owner wants to minimise the charging cost. Other optimisation algorithms and techniques, namely MILP, the fuzzy logic controller, is also available for such a multi-objective problem for charging points allocation.

In (Clemente et al., 2014), the authors have discussed the charging point allocation using mixed-integer linear programming. In the study, MILP is used for maximizing the user's utility by minimizing the charging cost. The cost of charging for an individual EV constitutes four factors - total waiting time, fixed cost of charging station, the cost associated with the distance between EV and charging station, and penalty cost for incomplete charging. This cost function is minimized considering various constraints, such as the assignment of an individual EV to a single charging point, assignment to any facility (V2G) only if its SOC level is sufficient, the time required to reach the desired SOC, charging station's capacity and completion of charging within the departure time. The study is performed with 50 vehicles and 5 charging stations with different charging points for 12 hours (48 slots with 15 minutes each slot).

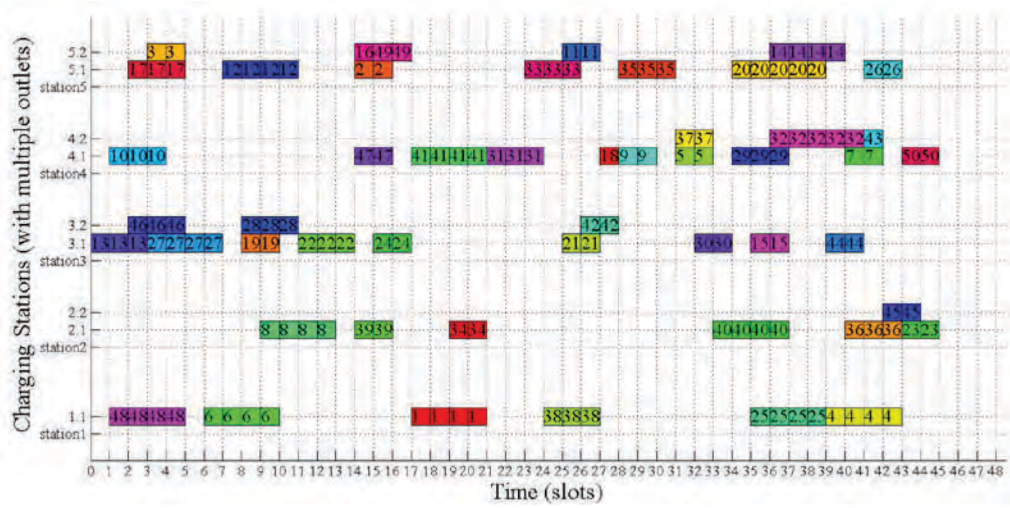


Figure 87: Optimal assignment and charging scheduling (Clemente et al., 2014)

The results in Figure 87 shows the allocation of charging points within different charging station. The coloured boxes indicate the EV allotted to a specific charging slot and charging point.

The study reported in (Yan et al., 2021) focuses on allocating charging power to each EV connected to a charging point within the charging station. The non-cooperative game theory approach has been used to solve the utility function of each EV. The utility function of EV is defined as the combination of requested power and charging preference (slow, fast, superfast). The method allocates optimal power, satisfying customer requirements and utility functions of individual EVs using the non-cooperative Nash equilibrium method. This equilibrium establishment is performed using two methods: centralised and distributed. The centralised method needs information of all the users at the energy time slot. Hence, it is not suitable for users' privacy and has less flexibility due to high concentric computational power requirements. In contrast, the distributed method is more secure in data privacy and more flexible due to distributed computation.

Hence, it is not suitable for users' privacy and has less flexibility due to high concentric computational power requirements. In contrast, the distributed method is more secure in data privacy and more flexible due to distributed computation.

The result in Figure 88 shows the optimal charging power allotted to each EV connected to the charging point in a charging station. The study considered seven EVs under two cases. Case-1 is when all EVs have the same charging preference value of 2 (urgency of charging), and Case-2 is when this preference value increases in an interval of 0.5 from two to seven.

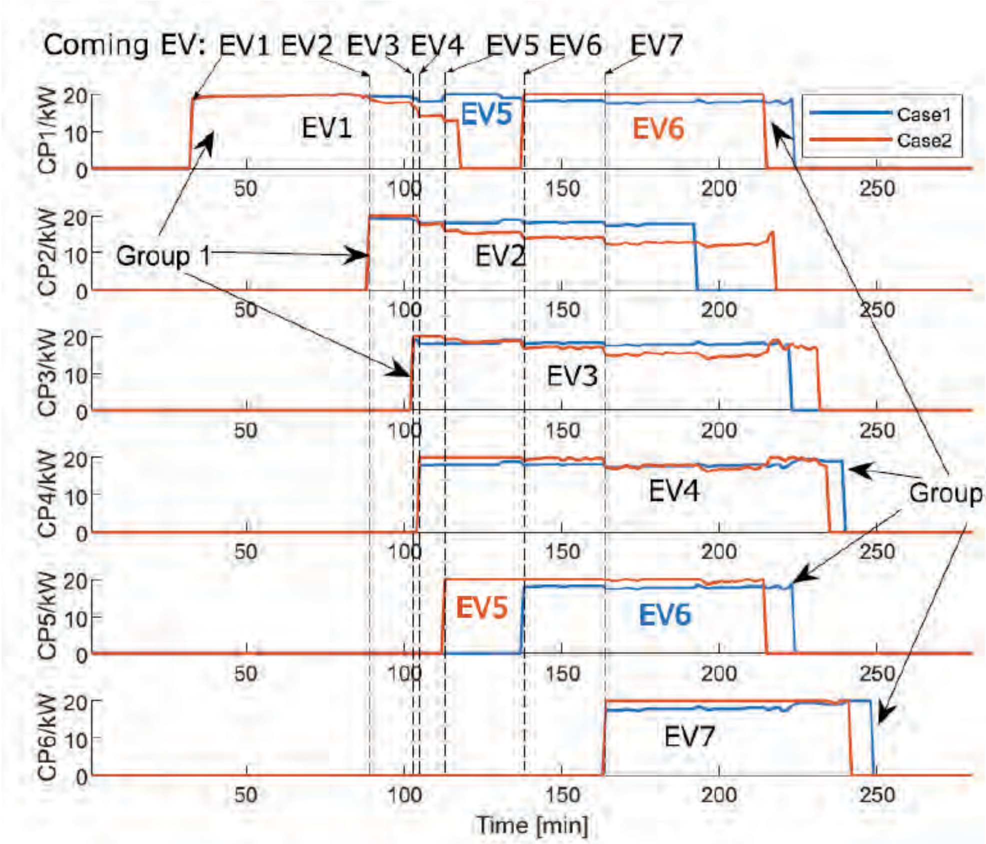


Figure 88: Charging coordination comparison (Yan et al., 2021)

The result depicts that all EVs are allocated with the same charging power in Case-1 because of the same preference values. In Case-2, the preference value of EV2 is low compared to others, so the charging interval of EV2 is increased and charging power is curtailed. EVs with higher preference values complete charging in advance, which increases the charging time of EVs with a lower preference value with a large charging window available.

The study in (Lee et al., 2018) covers the demonstration of load management at the control room of the Gwang-ju metropolitan city hall, Korea, in July 2018. Demonstration site charging station constitutes of solar photovoltaic generation system and EVs. Solar generation prediction, EV charging prediction, and load prediction are considered for energy management with charging stations. In this demonstration, study load management is performed for peak load reduction. The actual demonstration site and operators' interface is shown in Figure 89 and Figure 90 to give an idea of load management service for peak load reduction using smart charging coordination within the charging station.

Commercial products to coordinate charging point within the charging station discussed here is mentioned in Section 3.8.

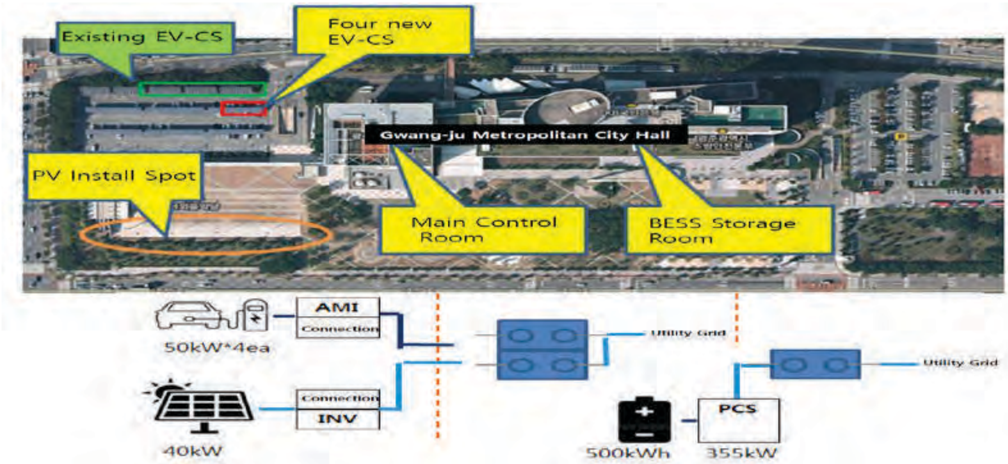


Figure 89: **Demonstration site of charging station (Lee et al., 2018)**

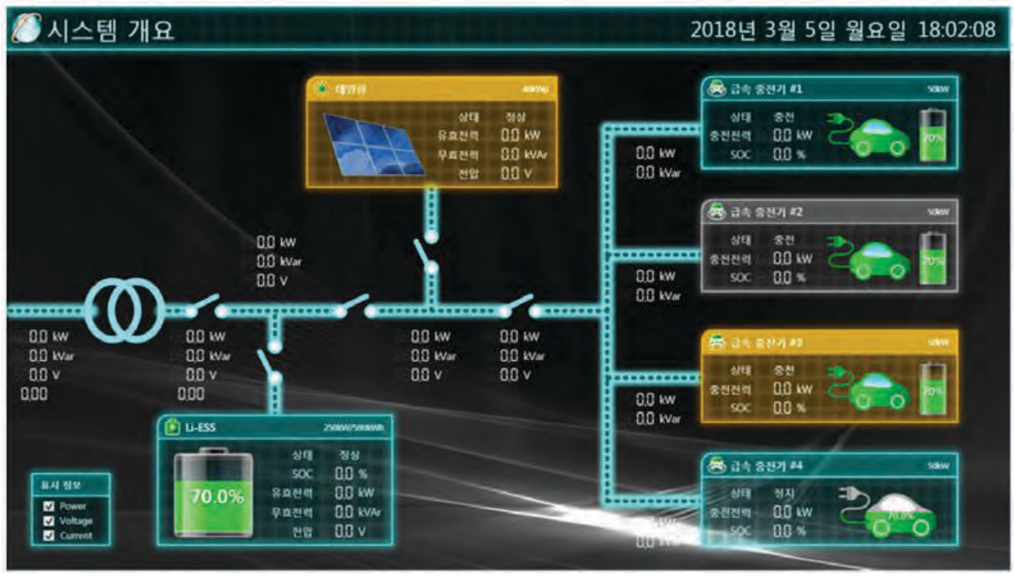


Figure 90: **Operator's user interface (Lee et al., 2018)**

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Conclusion and Way Forward

This report documents the overall landscape of smart charging including smart charging technology, smart charging strategies, smart charging solutions, and smart charging deployment projects. The international experience strongly suggests that smart charging is expected to play a key role in seamless adoption of EVs and charging infrastructure, open several avenues for grid support and grid management aspects, help in maximising RE utilisation, and cost effective EV management and grid operation. The next step includes the development of a robust framework for selecting key charging strategies and coordination approaches suitable to Indian context. The portfolio of these selected charging strategies will be used to conduct detailed grid modelling simulations using a reliable open source environment based on actual data from selected feeders in the distribution line of three cities in India. Load flow computations and state of the grid will be evaluated. Various test cases will be prepared and tested for different charging scenarios.

The large-scale deployment of electric vehicles can result in various protection related issues as the electrical characteristics of the distribution feeder will be altered depending on EV charging station distribution across the feeder and their charging behaviour. EV integration in the distribution feeder will affect the power flow pattern including reverse power flow, particularly in the presence of distributed energy sources. EVs can significantly influence the short circuit characteristics of a distribution feeder depending on the charging station capacity, charging strategy (slow/fast, controlled/uncontrolled), location and its response to a fault in the distribution feeder. Therefore, the next report will also investigate how EV integration can influence the short circuit aspects of a distribution feeder including the substation transformer, potential impact on existing protection coordination schemes considering balanced and unbalanced faults of different severity and duration. For instance, dynamic analysis involving short circuit/ fault analysis will be conducted.

The final report from this project will lay out set of comprehensive technical, policy and regulatory guidelines for smart charging of EVs in India for field implementation.

The final report from this project will lay out set of comprehensive technical, policy and regulatory guidelines for smart charging of EVs in India for field implementation. The development of such guidelines would depend upon how accurately and precisely the best fit strategies, business models, tariff structures, infrastructure reinforcement, demand response, consumer behaviour, international best practices etc. have been understood and considered. The learnings from the current report and the subsequent report(s) will be utilized to have the set of holistic guidelines for smart charging adoption in Indian EV ecosystem.

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Annexure I

Amendment: Technical Standards for Connectivity of the Distributed Generation Resources-2013, Central Electricity Authority

- **First Amendment- Feb 2019**

  This is associated with technical standards for Connectivity of the Distributed Generation Resources. The guidelines are issued for connectivity of EV charging station with the electricity system below 33 kV voltage level. The key provisions in the regulations are as follows:

  - EV charging station operator needs to provide a reliable protection system to detect various faults and abnormal conditions and provide an appropriate means to isolate the faulty equipment or system automatically
  - It would be the responsibility of the charging operator that fault in the EV charging infrastructure equipment or system does not affect the grid adversely.
  - DISCOM should carry out an adequacy and stability study of the network before permitting connection with its electricity system.
  - DISCOM to continuously measure and meter the harmonics with power quality meters complying with the provisions of IEC 61000-4-30 Class A
  - The charging operator needs to install power quality meters and share the recorded data with the DISCOM
  - DISCOM should periodically measure the voltage sag, swell, flicker, disruptions as per relevant IEC standard

- **Second Amendment- June 2019**

  This amendment covers the Safety and Electric Supply Regulations, which laid down several safety provisions for EV charging infrastructure connected with the grid. The key provisions are as follows:

  - All electric vehicle charging stations are required to protect against the overload of input supply and output supply fittings
  - All electric vehicle charging points should have a socket-outlet of supply at least 800 millimetres above the finished ground level
  - A suitable lightning protection system needs to be provided as per Indian Standards Code IS/ IEC 62305
  - All residual current devices used to protect supplies to electric vehicles must be permanently marked to identify their function and the location of the charging station or socket outlet they protect.
  - Each electric vehicle charging point needs to be supplied individually by a dedicated final sub-circuit protected by an overcurrent protective device complying with IEC 60947-2, IEC 60947-6-2 or the IEC 60269 standards, and the overcurrent protective device should be part of a switchboard.
  - The enclosure of charging stations should be made of fire-retardant material with self-extinguishing property and free from Halogen
  - Power supply cables used in charging stations or charging points should conform to IEC 62893-1 and its relevant parts.
  - All apparatus of charging stations should have the insulation resistance value as stipulated in the relevant IEC 61851-1
  - The charging station owner needs to establish and implement a safety assessment program for regular periodic assessment of the electrical safety of the charging station. Electrical inspectors and/or Chartered Electrical Safety Engineers are entrusted with the responsibility of testing and inspection of charging infrastructure
  - The charging station owner needs to keep records of the results of every inspection, testing and periodic assessment and details of any issues observed during the assessment and any actions required to be taken concerning those issues.

- The safety provisions of all Alternating Current charging stations should be in accordance with IEC 61851-1, IEC 61851-21, and IEC 61851-22.
- The safety provisions of all Direct Current charging stations should be in accordance with IEC 61851-1, IEC 61851-21, IEC 61851-23, and IEC 61851- 24.

Charging Infrastructure for Electric Vehicle-Revised Guideline and Standard issued by MoP

Provisions mentioned in “Charging Infrastructure for electric vehicle-Revised Guideline and standard” issued by MoP is discussed below.

Mandatory Provisions:

- The regulation permits the installation of a private charging station at residences and workplaces. This will help to lower the issue of insufficient charging facilities for EV owners.
- The regulation allows any person or company to establish a charging station by adhering to all the technical, safety, and performance standards and protocols.
- The regulation suggests the DISCOMs to provide electricity connections to charging stations on a priority basis. In addition to this, the charging station can also procure electricity from any generating station through open access.
- Minimum requirement of public charging station (PCS) such that PCS must have at least one or more or any combination of charging points as stated in the regulation are given in Table 18.

Table 18: Minimum requirement of the public charging station as per MoP-issued regulation for charging infrastructure of electric vehicles

Charging type	Sr. No	Connector type	Rated output voltage(V)	No. of connector	Vehicle type (W=Wheels)
Fast	1	CCS (min 50 KW)	200-750 or higher	1	4
	2	CHAdeMO (min 50 KW)	200-500	1	4
	3	Type 2 AC (min 22 KW)	380-415	1	4W, 3W, 2W
Slow/ Moderate	4	Bharat DC-001(15 KW)	48	1	4W, 3W, 2W
	5	Bharat DC-001(15 KW)	72 and higher	1	4W
	6	Bharat AC-001(10 KW)	230	3	4W, 3W, 2W

- Charging stations for 2W and 3W are free to install any of the above or any other type of charger.
- The above-mentioned infrastructure requirement is not compulsory for private, self, home, non-commercial charging stations, and company-owned internal fleet, but it must satisfy the technical and safety standards laid down by CEA.
- The charging station must tie up with at least one Network Service Provider to ensure remote and online booking, which will further help establish smart charging.
- The charging station must share data with DISCOM such that Central Nodal Agency (CNA) and State Nodal Agency (SNA) must have access to the data.
- An authorised agency must test electric vehicle charging equipment (EVSE) from time to time.
- The above-mentioned mandates regarding the number of charging points are not compulsory for private, non-commercial, and captive charging stations.
- Provision related to heavy-duty vehicles states that “at least two charging points with a minimum rating of 100 kW (200-750V or higher) with different charger type (CCS, CHAdeMO or any DST or BIS approved charger) with a single gun should be present”.
- About location and distance between charging stations, the regulation states, “at least one charging station should be established in a grid of 3 km x 3 km and at every 25 km on both sides of highway whereas there should be one charging station with the specified specification at every 100 km for long-range heavy-duty vehicles.”

- The special commission should decide the tariff structure for EV charging. This tariff is applicable to separately metered public charging stations only. A domestic charging station must be billed using domestic tariff charges.
- The regulation states that if PCS is installed with government incentives, then state nodal agency/state agency will decide the celling of service charges levied by PCS.

Optional provisions:

- A transformer with related substation equipment and safety appliance should be installed.
- Appropriate civil work, cabling work, and electric safety shall be maintained.

The regulation includes the timeline for the roll-out of EV charging infrastructure in the nation. According to the mentioned timeline, Phase-1 (1-3 years) should cover all megacities with population greater that 40 lakh, important express ways, and highways connecting mega cities. In Phase-II (3-5 years), the state capitals, Union Territories headquarters and other important highways must be covered.

The central nodal agency is responsible for maintaining the appropriate mode of implementation. It works with state nodal agencies and other government bodies. The nodal agencies and their roles are presented in Table 19.

Table 19: Issuing agency and role of nodal agencies

Nodal agency	Name of agency	Purpose/Work of agency
Central Nodal Agency (CNA)	Bureau of Energy Efficiency (BEE)	Finalize cities, highways, and expressways for priorities
State Nodal Agency (SNA)	The state government is free to choose any PSU, Urban local body as a nodal agency.	To choose an implementation agency responsible for installation, operation, and maintenance for a specified period of time.

EV tariff Regulations

• Delhi

The electricity tariff structure specified for EVs by the government of Delhi is tabulated below, compared with residential and commercial tariffs. Various states have defined specific demand charges along with their energy charges for EV consumers. Table 20 compares tariffs and demand charges for Delhi for different load categories (Delhi Electricity Regulatory Commission).

Table 20: EV tariff structure in Delhi

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 4.5/kWh (Supply at LT) and ₹ 4.0/ kVAh (Supply at HT)	Nil
Residential Tariff	₹ 3 to ₹ 8/ kWh	₹ 125 to ₹ 250/kW per month
Commercial Tariff	₹ 8.0/kVAh	₹ 250/kVA per month

Delhi government has implemented a Time-of-use tariff structure, as shown in Table 21 (Delhi Electricity Regulatory Commission). Time-of-use tariff-based charging is a smart charging strategy. It is a simple, less expensive, but effective smart charging method applicable to all commercial, public charging stations. Special electricity tariff is applicable to commercial captive and private charging stations connected to a central management system. This timely price-based smart charging is applicable at all the above-mentioned charging stations.

Table 21: Time-of-use (ToU) tariff structure of Delhi

Months	Peak Hours (Hrs)	Surcharge on Energy Charges	Off-Peak Hours (Hrs)	Rebate on Energy Charges
May - September 2020	1400– 1700	20%	04:00 – 10:00	20%
	2200 – 0100			

- **Karnataka**

The EV tariff structure for Karnataka state is given in Table 22 (Karnataka Electricity Regulatory Commission, 2020):

Table 22: EV tariff structure of Karnataka

Category	Electricity Tariff- 2021	
	Energy Charge	Demand Charge
EV tariff	₹ 5.00/kWh	₹ 70/kW per month and ₹ 200/ kVA per month
Residential Tariff	₹ 4.00 to ₹ 8.05/ kWh	For first kW: ₹ 70/kW per month For every additional kW: ₹ 80 /kW
Commercial Tariff	For 1 Lakhs unit: ₹ 7.35 /unit For balance units: ₹ 7.65 /unit	₹ 230/kVA per month

- **Maharashtra**

The EV electricity tariff, along with residential and commercial tariff structure for Maharashtra, is given in Table 23 (Maharashtra Electricity Regulatory Commission, 2020b):

Table 23: EV tariff structure of Maharashtra

Category	Electricity Tariff (FY 20-21)	
	Energy Charge	Demand Charge
EV tariff	₹ 5.06/kWh	₹ 70/kVA/ Month
Residential Tariff	₹ 3.46 to 11.71/kWh	₹ 100/kVA per month
Commercial Tariff	₹ 7.36/kW (LT) & ₹ 11.47/ kVAh (HT)	₹ 403 kW & ₹ 411/ kVA per month

Maharashtra has adopted a time-of-use tariff-based smart charging strategy. This smart charging strategy helps in addressing renewable intermittency and maximum utilization of clear and cheap generations. Time-of-use based tariff is divided into surcharge and rebate. The tariff is divided for LT load (up to 20kW) and HT (above 20 kW) load based on the sanctioned load value. In this tariff structure, surcharge and rebate are applied on fixed energy costs (Rs/kWh). The tariff structure for public LT and HT charging stations is given in Table 24 and Table 25 (Maharashtra Electricity Regulatory Commission, 2020a).

Table 24: Tariff structure for LT charging station load in Maharashtra

Consumption Slab (kWh)	Fixed Charge / Demand Charge	Wheeling Charge (Rs/kWh)	Energy Charge (Rs/kWh)
All Units	Rs. 70 per kVA	1.57	3.93
TOD Tariffs (in addition to above base Tariff) (FY 20-21)			
Time Interval		Energy charges (Rs/kWh)	
0600 to 0900 hours		0.00	
0900 to 1200 hours		0.50	
1200 to 1800 hours		0.00	
1800 to 2200 hours		1.00	
2200 to 0600 hours		-0.75	

Similarly, the tariff structure for HT EV charging and swapping stations is given below [1].

Table 25: Tariff structure for HT charging station load in Maharashtra

Consumption Slab (kVAh)	Fixed Charge / Demand Charge	Wheeling Charge (Rs/ kVAh)	Energy Charge (Rs/kVAh)
All Units	Rs. 70 per kVA	0.70	4.61
TOD Tariffs (in addition to above base Tariff) (FY 20-21)			
Time Interval		Energy charges (Rs/kVAh)	
0600 to 0900 hours		0.00	
0900 to 1200 hours		0.50	
1200 to 1800 hours		0.00	
1800 to 2200 hours		1.00	
2200 to 0600 hours		-0.75	

These ToU charges are applicable to commercial, public charging stations.

• Andhra Pradesh

The EV electricity tariff, along with residential and commercial tariff structure for the state of Andhra Pradesh, is given in Table 26 (Andhra Pradesh and Electricity Regulatory Commission, 2020):

Table 26: EV tariff structure of Andhra Pradesh

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 5/kWh (LT) and ₹ 5/kVAh (HT)	Nil
Residential Tariff	₹ 1.45 to ₹ 9.05/kWh	Nil
Commercial Tariff	₹ 5.4 to ₹ 10.15/ kVAh	₹ 55 to ₹ 75/kW per month

• Kerala

The EV tariff structure for the EV charging station is presented in Table 27.

Table 27: EV tariff structure of Kerala

Load type	Connected load	Fixed charges per demand 2020-21	Energy charges 2020-21 (Rs/kWh)
LT	Connected load of and below 10 kW	200	4.50
	Connected load above 10 kW and up to 20 kW	200 / kW	4.50
	Connected load above 20 kW	500 /kVA	4.50
HT	HT charging stations	315 (Rs/kVA)	5 (Rs/ kWh)

Time-of-use EV tariff structure for EV charging station is showed in Table 28.

Table 28: Time-of-use tariff structure in Kerala

Category	06:00-18:00	18:00-22:00	20:00-06:00
Energy Chargers	50%	100%	75%
Energy Chargers above 500 unit consumed	100%	120%	90%

• Uttar Pradesh

For Uttar Pradesh, the EV electricity tariff along with residential and commercial tariff structure is given in Table 29:

Table 29: EV tariff structure of Uttar Pradesh

Category	Electricity Tariff (FY 19)	
	Energy Charge	Demand Charge
EV tariff	₹ 5.9 to ₹ 7.7/ kWh	Nil
Residential Tariff	₹ 3 to ₹ 6.5/ kWh	₹ 50 to ₹ 100/kW per month
Commercial Tariff	₹ 5 to ₹ 18/kWh	₹ 95 to ₹ 430/ kW per month

Summer Months (April to September) Hours	% of Energy Charges
05:00 hr – 11:00 hr	(-) 15%
11:00 hr – 17:00 hr	0%
17:00 hr – 23:00 hr	(+) 15%
23:00 hr – 05:00 hr	0%

Table 30: Time-of-use (ToU) tariff structure of Uttar Pradesh for summer months

Time of use tariff structure for smart charging is given in Table 30 and Table 31 (Uttar Pradesh Electricity Regulation Commission, 2019). Uttar Pradesh has issued different ToU charges for summer and winter based on variable peak load timing.

Table 31: Time-of-use (ToU) tariff structure of Uttar Pradesh for winter months

Winter Months (October to March) Hours	% of Energy Charges
05:00 hr – 11:00 hr	0%
11:00 hr – 17:00 hr	0%
17:00 hr – 23:00 hr	(+) 15%
23:00 hr – 05:00 hr	(-) 15%

• Gujarat

The EV electricity tariff, along with residential and commercial tariff structure for Gujarat, is given in Table 32 (Madhya Gujarat Vij Company Limited (MGVCL), 2020):

Table 32: EV tariff structure of Gujarat

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 4 to ₹ 4.1/ kWh	• ₹ 25 per month per installation • ₹ 25 to ₹ 50 per kVA per month
Residential Tariff	₹ 3.05 to ₹ 5.2/ kWh	₹ 15 to ₹ 70 per month
Commercial Tariff	₹ 4.35 to ₹ 4.65/ kWh	₹ 50 to ₹ 195/ kW per month

• Madhya Pradesh

The EV electricity tariff, along with residential and commercial tariff structure for Madhya Pradesh, is given in Table 33 (Madhya Pradesh Electricity Regulation Commission, 2020):

Table 33: EV tariff structure of Madhya Pradesh

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 5.9 to ₹ 6.0/kWh	₹ 100 per kVA to ₹ 120 per kVA of Billing Demand
Residential Tariff	₹ 3.25 to ₹ 6.65/ kWh	₹ 35 to ₹ 90 per connection
Commercial Tariff	₹ 6.1 to ₹ 8.5/kWh	₹ 55 to ₹ 260/ kW per month

• Telangana

For Telangana, the EV electricity tariff along with residential and commercial tariff structure is given in Table 34 (Telangana State Electricity Regulatory Commission, 2018-19):

Table 34: EV tariff structure of Telangana

Category	Electricity Tariff (2018-19)	
	Energy Charge	Demand Charge
EV tariff	₹ 6.00/kWh	Nil
Residential Tariff	₹ 1.45 to ₹ 9.5/ kWh	Nil
Commercial Tariff	₹ 5.3 to ₹ 12.0/ kVAh	₹ 50 to ₹ 60/kW per month

Special power tariff ToU structures for eligible charging stations are provided in Table 35 (Telangana State Electricity Regulatory Commission).

Table 35: Time-of-use (ToU) tariff structure of Telangana

Time interval	Additional charges on energy price (Rs/kWh)
6 AM-10AM	7.00
6PM-10PM	7.00
10PM-6AM	6.00

• Punjab

For Punjab, the EV electricity tariff along with residential and commercial tariff structure is given in Table 36 (Punjab Electricity Regulation State Commission, 2020):

Table 36: EV tariff structure of Punjab

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 6/kVAh	Nil
Residential Tariff	₹ 4.99 to ₹ 7.30/kWh	₹ 35/kW to ₹ 110/kVA per month
Commercial Tariff	₹ 6.35 to ₹ 7.29/ kWh	₹ 45/kW to ₹ 110/kVA per month

- **Bihar**

The EV electricity tariff, along with residential and commercial tariff structure in Bihar, is given in Table 37 (Bihar Electricity Regulatory Commission, 2020):

Table 37: EV tariff structure of Bihar

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	Same tariff for EV as the respective category rate	Nil
Residential Tariff	₹ 6.15 to ₹ 8.60/ kWh	₹ 20 to ₹ 40/kW per month
Commercial Tariff	₹ 6.4 to ₹ 7.5/ kWh	₹ 30 to ₹ 180/ kW per month

- **Haryana**

The EV electricity tariff, along with the residential and commercial tariff structure of Haryana state, is given in Table 38 (Haryana Electricity Regulatory Commission, 2020):

Table 38: EV tariff structure of Haryana

Category	Electricity Tariff (FY 20)	
	Energy Charge	Demand Charge
EV tariff	₹ 5.58/kVAh or ₹ 6.2/kWh	₹ 100/kW per month
Residential Tariff	₹ 2.0 to ₹ 7.1/ kWh	Nil
Commercial Tariff	₹ 6.65 to ₹ 7.35/ kVAh	₹ 160/kW-180/kW per month

Technical Specification of Bharat AC 001 and Bharat DC001

Specifications of Bharat AC 001 and DC 001 standards issued by CEA is given in Table 39 below.

Table 39: Technical specification of Bharat AC001 and DC001

Parameter	Bharat AC001	Bharat DC001
General requirements		
EVSE type & mode of charging	AC EVSE & conductive charging	DC EVSE (Dual connector) & conductive charging
Input Parameters		
Input voltage	3-phase, 415 V	3-phase, 415 V
Output parameter		
No of output guns	3	2
Output voltage	1-phase, 230V	48V/60V/72V as per battery requirement
Maximum current	15 A	200 A
Connector	IEC 60309	One connector with GB/T 20234.3 and one yet to finalised
Limiting output current	16 A	-
Isolation	Class 1 and class 2 as per AIS 138(3.3.1 and 3.3.2)	-
Environmental Requirement		
Ambient temperature	0-55 degree Celsius	0-55 degree Celsius
Ambient humidity	5-95%	5-95%

Parameter	Bharat AC001	Bharat DC001
Ambient Pressure	86-106 kpa	86-106 kpa
Storage temperature	0-60 degree Celsius	0-60 degree Celsius
Mechanical Requirement		
Cable security	Physical locking mechanism	
Mechanical stability	Should withstand 20J	
IP rating	IP 54	IP 54
Cooling	Air cooling	Air cooling
Display Requirement		
Start-stop switch	Mandatory	Mandatory
Emergency stop switch	Present	Present
Visual Indicator	Error indication, presence of input supply, charge process indication	Error indication, presence of input supply, charge process indication
Display size	Minimum 3.5 inches, 720 x 480 pixel, touch screen and keypad	Minimum 3.5 inches, 720 x 480 pixel, TFT LCD screen touch screen and keypad
User authentication	Mobile interface or user interface (as per OCPP)	Mobile interface or card reader (as per OCPP)
Payment requirement		
Payment options	BHIM/ Bharat QR/ UPI	BHIM/ Bharat QR/ UPI
Communication requirement		
Communication between EVSE and central server	OCPP 1.5 or higher versions	EVSE- EV: CAN communication EVSE-central management system: Ethernet /Wifi/2G/3G/4G EVSE-central server: OCPP 1.5 or higher

Furnishing Information of Public Charging Station to CEA

Formats for data collection from DISCOMS and charging stations are provided in Table 40 below.

Table 40: Formats for data collection from DISCOMS

DISCOM	Circle or Zone	Station Name	Location						Station type (self-service/ attendant)
			Address	Latitude	Longitude	City	State	PIN	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

Station Phone No.	Access type (Public/ Private/ Captive/ Restricted)	Access time (24hr/8AM-10PM)	Payment mode (Cash/e-wallet)	Commissioning date	Owner	Connector type	No. of Level-1 EVSE
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)

No. of level-2 EVSE	No. of DC fast charger	AC input voltage	DC output
(19)	(20)	(21)	(22)

Information on the electricity consumption of charging stations collected by DISCOMs is collected in the format shown in Table 41.

Table 41: **Electricity consumption information of charging station**

DISCOM	Month	No. of charging station under DISCOM	No. of vehicle charged	Electricity consumption during month
(1)	(2)	(3)	(4)	(5)

Retrofitting of Hybrid Electric Vehicle

Retrofitting of various categories of hybrid vehicle systems with their compliance standards and requirements are given in Table 42 below.

Table 42: **Type, requirement, and compliance standard for retrofitting**

Sr. No.	Type of retrofitting	Compliance standard	Requirement for retrofitting
1	Retrofitting of Hybrid Electric System Kit to vehicles of categories L, M and N having Gross Vehicle Weight not exceeding 3500 kg	Requirements stipulated in *AIS-123 (Part 1) should confirm	1. Retrofitting vehicle must follow Bharat stage-II or higher versions of emission norms. 2. It must belong to M1/M2/N1 with a weight less than 3500Kg. 3. Vehicle should be gasoline and diesel, not alternative fuelled and must not be retrofitted before.
2	Retrofitting of Hybrid Electric System Kit to vehicles of categories M and N having Gross Vehicle Weight exceeding 3500 kg	Requirements stipulated in *AIS-123 (Part 2) should confirm	1. Retrofitting vehicle must follow Bharat stage-II or higher versions of emission norms. 2. It must belong to M1/M2/N1 with a weight greater than 3500Kg which is not retrofitted earlier. 3. It should not have a permit for carrying dangerous and hazardous goods defined in CMV rule 1989.
3	Conversion of motor vehicles for pure electric operation with the fitting of the Pure Electric Propulsion Kit by replacing the engine of Motor Vehicles of categories L, M, N	Requirements stipulated in *AIS-123 (Part 3) should confirm	-

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