Azadi Ka Amrit Mahotsav

विज्ञान और प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE AND TECHNOLOGY
सत्यमेव जयते

R&D Roadmap on

EV Charging Infrastructure

TECHNOLOGIES TO OVERCOME HINDRANCES TO E-MOBILITY

VOLUME No. 3

R&D Roadmap on

EV Charging Infrastructure

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[Note: Thematic report based on DST’s White Paper on Catalysing Technology-Led Ecosystem for e-Mobility].

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Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

17th October, 2024

MESSAGE

India's commitment to achieve a Net-Zero emission target by 2070 and reducing carbon emissions by one billion tonnes by 2030 underscores the critical need for a transition to electric mobility. India aims to achieve 30% EV market share by 2030. Spurred by encouraging initiatives by the Government of India, EV industry is growing at faster pace and automotive industry is gearing up to ramp up their operations to meet domestic demand. Many innovative start-ups have also ventured into this domain.

While there is significant growth in this sector, there are still many challenges that needs to be addressed for effective EV adoption in the country. At present, the industry depends heavily on imported materials/components due to lack of domestic supply chain and manufacturing capabilities in the country. This calls for a strategy and intervention in developing indigenous R&D capabilities to strengthen the capacity and capability of Industry for long term sustainability and end-to-end value creation across the value chain.

In this context, the Department of Science and Technology (DST) has prepared EV R&D Roadmaps to assess existing technology gaps and propose viable solutions. These documents aim to establish an industry-focused R&D roadmap for the development of indigenous components, processes, and technologies that will benefit the sector. Two year-long intensive consultation process involving over 200 stakeholders has culminated in these R&D Roadmaps, which focus on Tropical EV Batteries, Power Electronics, Machines and Drives and EV Charging Infrastructure.

With the establishment of the Anushandhan National Research Foundation (ANRF), DST is well-positioned to concentrate on clean energy and decarbonization pathways, under EV Mission, which has been recently launched, guiding India's energy transition and working towards the goal of Net Zero by 2070.

I would like to commend the DST team for their tremendous efforts and acknowledge the invaluable contributions of domain experts from academia, industry, and ecosystem partners in producing these crucial insights for e-Mobility.

I am confident that this document will serve as an important reference guide for the R&D community and will drive new advancements in industry-oriented R&D initiatives for e-Mobility in India.

(Abhay Karandikar)

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सत्यमेव जयते
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MESSAGE

In the effort to decarbonise India, the mobility sector is undergoing significant transformation, with Electric Vehicles at the forefront as a sustainable solution for the future. India aspires to become a global manufacturing hub for electric vehicles.

To achieve this ambitious goal and foster an environment conducive to innovation, Department of Science and Technology (DST) had launched a pioneering initiative to prepare R&D Roadmaps on three key areas: Tropical EV Batteries, EV Power Electronics and Machine and Drives and EV Charging Infrastructure. These documents analysed current capabilities, identify gaps and challenges and proposed actionable strategies to accelerate advancement in indigenous technologies while building a robust R&D and manufacturing eco system.

A key focus is establishing self-reliant battery ecosystem which include setting up of pilot production facilities for battery cell manufacturing. In case of power electronics and machine drives, it is envisaged to develop market driven products through creation of Centres of Excellence (CoEs). These R&D Roadmaps also address supply chain challenges related to essential materials like lithium salts and rare earth oxides under scoring the need for standardized processing technologies to support extraction, product development and recycling of end-of-life products. Further, low cost, innovative solutions have been proposed to enhance the ease of doing business in EV charging infrastructure sector.

I would like to extend my heartfelt thanks to the Advisory Committee led by Prof. B.G. Fernandes from IIT Bombay, and to the expert members for their invaluable contributions in crafting these R&D Roadmaps with high quality content, in-depth analysis and actionable framework. Lastly, I appreciate the efforts of my colleague, Mr. Suresh Babu Muttana, Scientist-E, DST in engaging with industry experts and stakeholders which has resulted in rich insights that shaped these R&D roadmaps.

I am hopeful that these documents will not only promote technological advancements but also cultivate vibrant R&D eco-system for electric mobility in the country.

(Dr. Anita Gupta)

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MESSAGE

Electric Vehicles are sustainable alternatives to Internal Combustion Engines (ICEs) as they produce zero local emissions and reduce dependence on imports of fossil fuels thereby ensuring energy security. Spurred by favourable schemes and policies by the Government of India, Indian Electric Vehicle sector has shown remarkable growth over the last few years.

With growth, there are still many challenges that need to be addressed for effective adoption of EVs in the country. These include the high cost of vehicles, limited range, concern about vehicle safety and lack of adequate charging infrastructure. In addition, innovation, design and development to increase efficiency and performance of the EVs and testing competency are also need attention. In this context, Department of Science and Technology (DST) in consultation with various stakeholders brought out a consolidated White Paper on *EV Evolution: Catalysing Technology led Ecosystem for e-Mobility,* which was released in the month of February, 2024. This document highlighted both hindrances being faced and also provided technology solutions to address these issues to strengthen Indian EV industry through R&D intervention.

DST is now bringing out three R&D roadmap documents on EV battery, EV motors and power electronics, and EV charging infrastructure, which have been prepared after extensive consultations with the stakeholders over a period of two years. These documents are crucial for setting up R&D targets and work towards developing indigenous products/systems that conform to international standards to help industry to meet domestic market and as well increase export potential in this domain.

I extend my sincere gratitude to Dr. Abhay Karandikar, Secretary, DST for giving me the opportunity to Chair the Advisory Committee. I also thank Dr. Anita Gupta, Head, Climate, Energy and Sustainable Technology (CEST), DST for her support in this endeavour. Special thanks to members of the Advisory Committee, especially Prof. Siddhartha Mukhopadhyay, for their valuable contributions in shaping these documents.

I hope that these documents are of use for planning and implementation of R&D programmes in promoting research and advancing domestic manufacturing competencies in achieving the targets of Atma Nirbhar Bharat (Self-Reliance).

Prof. B.G. Fernandes
Chairman, Advisory Committee
White Papers on e-Mobility, DST

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GENESIS AND KEY CONTRIBUTORS

NITI Aayog entrusted DST to work on technologies to overcome hindrances in e-Mobility. Over the last two years, DST conducted a series of interactions with stakeholders viz. vehicle OEMs, battery manufacturers, electrical & electronics industry, R&D labs, academia and think tanks to identify key challenges and potential R&D solutions to address these issues. These deliberations led to preparation of a White Paper on Catalysing Technology led Ecosystem for e-Mobility, which was released on 28.02.2024 by Dr. Jitendra Singh, Hon'ble Minister of State (I/C) for Science & Technology, GoI.

As an extension to the above effort, DST has now come up with detailed R&D Roadmaps in key thrust areas of electric mobility viz. (a) Tropical EV battery, (b) Power electronics, Machines and Drives; and (c) EV charging infrastructure. These reports have gone through several iterations and inputs received from major auto industries and other stakeholders from the entire EV ecosystem have been incorporated.

I would like to express sincere gratitude to Prof. Abhay Karandikar, Secretary, Department of Science & Technology (DST), GoI for his kind support and overall guidance. I would like to thank Dr. Anita Gupta, Head, CEST Division, DST for her concerted efforts and guidance in shaping the recommendations as well as program plans aligned with national goals.

I also extend deeper appreciation to the Advisory Committee led by Prof. B.G. Fernandes, IIT Bombay, and the noteworthy contributions by domain experts namely: Dr. K Raghunathan, IIT Madras; Prof. Siddartha Mukhopadhyay, IIT Kharagpur; Mr. Sajid Mubashir (former), DST; Dr. Z.V. Lakaparampil (former), CDAC ; Mr. Suuhas Tendulkar, ERF Global; Ms. Veena Koodli, Robert Bosch; Mr. N. Mohan, CESL; Mr. Kiran Deshmukh, Sona Comstar, who have extensively contributed in preparation of these R&D Roadmaps with quality content and in-depth analysis and actionable framework.

I would like to express sincere thanks to the lead authors: Ms. Moushumi Mohanty, Ms. Mrinal Tripathi, Mr. Rohit Garg, Ms. Anannya Das, Centre for Science and Environment (CSE); Dr. Raghunathan, IIT Madras; Mr. Sajid Mubashir (retired), DST; Mr. Arghya Sardar, TIFAC; Dr. Parveen Kumar, WRI India; Mr. Suuhas Tendulkar, ERF Global; Ms. Veena Koodli- Robert Bosch; and Mr. N Mohan, CESL, who have put together initial drafts and also immensely contributed in finalisation of these documents. I would like to acknowledge especially Dr. Reji Mathai, Director, ARAI for reviewing R&D Roadmap on EV Charging Infrastructure.

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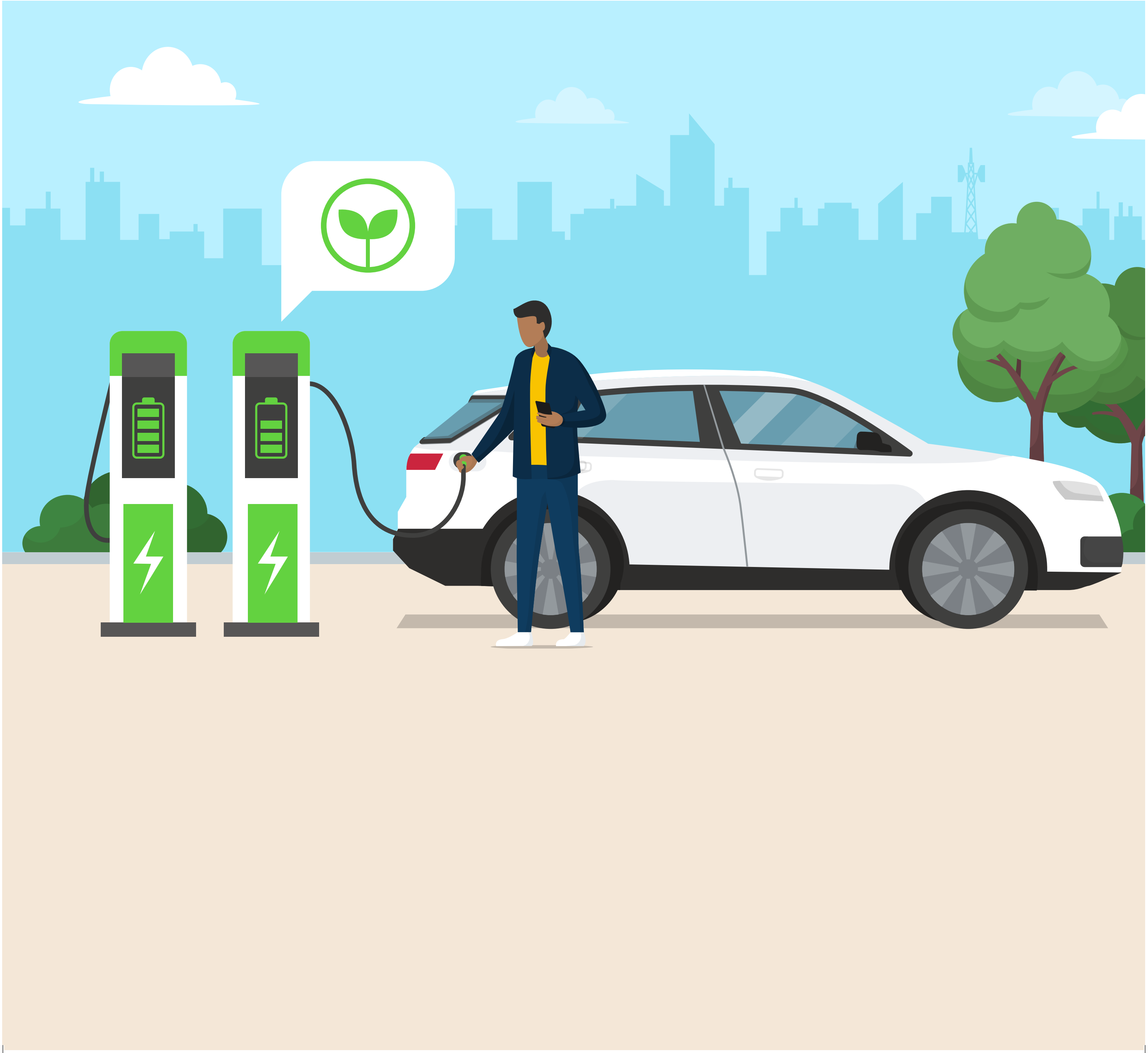
CONTENTS

विज्ञान और प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE AND TECHNOLOGY
सत्यमेव जयते

EXECUTIVE SUMMARY



EV CHARGING INFRASTRUCTURE in India needs to adequately meet the low-power requirement of LEVs that comprise more than 90% of the total EV population. At the same time, the infrastructure also needs to be ready for supporting high-power fast charging to fulfil the country's ambitions in transitioning to e-buses and e-freight. In addition to these distinct challenges, an additional expectation is to meet globally acceptable technical and service standards of delivery.

Keeping the importance of this sector, Government of India has formulated multiple policies and incentive schemes to promote the deployment of electric vehicles (EVs) and charging infrastructure throughout the country. Most states have also developed their own EV policy visions and incentive mechanisms. Both central and state-level policies acknowledge the critical role of EV charging infrastructure in facilitating the widespread adoption of EVs. These policies aim to address two significant issues:

- Ease of doing business in the electric vehicle charging industry
- Ease of access to charging infrastructure for consumers

The EV charging Infrastructure guidelines highlights a few important aspects. Firstly, the timelines for providing connections for EV charging are as per the Electricity (Rights of Consumers) Rules, 2020. Both consumers and prosumers have the same rights, and the reliability of supply is considered a consumer right. Public charging stations must adhere to technical, safety, and performance standards. Furthermore, public charging infrastructure for fast charging will require a high-tension (HT) connection, an exclusive transformer, civil works, and adequate space for vehicle entry and exit. Additionally, public charging stations may be installed by housing societies, malls, office complexes, restaurants, hotels, and other establishments to facilitate the charging of visitors' vehicles.

However, there have been challenges in the implementation of these guidelines, particularly in enabling widespread charging infrastructure suited to Indian requirements and conditions. These has generated several opportunities for small entrepreneurs, and proactively creating new indigenous product offerings in the EV charging infrastructure. Another critical issue is ensuring ease of charging access for consumers by enabling robust system integration and seamless interoperability across hardware and software interfaces.

This white paper addresses these specific issues and presents an architecture for EV infrastructure aligned with national policy objectives. It explores the best ways to charge light electric vehicles (LEVs) and hatchback cars, which require lower charging power (approximately 30kW or less), and the optimal charging methods for electric buses. It also discusses how to ensure simple and uniform charging services for EV customers at any location and at any time and identifies areas within the EV charging ecosystem that need technology development and demonstration support to develop indigenous, cost-effective, and practical solutions.

In line with the above understanding, the R&D Roadmap is divided into four sections:

> **Section 1:** LEV Charging Infrastructure
>
> **Section 2:** HEV Charging Infrastructure
>
> **Section 3:** Interoperability in EV Charging
>
> **Section 4:** Technology Support Areas for EV Charging Infrastructure.

Each of the above sections attempts to encapsulate the status of infrastructure development and then highlights the key barriers and proposed support needs, particularly focusing on solutions that may require support in TRL 4 – TRL 6 band.

Section 1- LEV charging infrastructure

In the short- to medium- term, the battery capacity for LEVs is expected to remain below 15kWh due to space and pricing constraints. Currently, most of the LEV ecosystem operates with battery voltages ranging from 48V to 72V. For a 48V system with a 210Ah battery pack and a 0.5C realistic charging rate, the maximum power requirement is around 6kW. Similarly, for LEV batteries in the 96V-120V range, the maximum power requirement would generally not exceed 12kW. Even for a future 120V system with a 125A charging current, the maximum power requirement is projected to be no more than 15kW (250Wh/min).

> » Indian standards for LEV charging define several charging capacities:
>
> » Alternate current (AC) charging up to It is 3 kW (IS-17017-22-1)
>
> » Direct current (DC) charging up to 12kW (IS-17017 Part2/Sec6)
>
> » Combined AC/DC charging systems, also known as Light Electric Combined Charging Systems (LECCS), with AC up to 7kW and DC up to 12kW (IS-17017 Part2/Sec7).

Key barriers and technology interventions needed

1. **Public fast charging infrastructure:** All public fast chargers are currently DC chargers, and it is anticipated that LEV public charging will predominantly remain DC. For widespread EV adoption and the establishment of charging infrastructure, there is a need for the mass manufacturing of indigenous LEV DC chargers (12kW) to improve affordability and facilitate faster deployment. Presently, the level of indigenization is limited as most charger components are imported. Supporting the indigenization of LEV DC chargers through product development initiatives (industry-academia collaboration) and local manufacturing can enhance the penetration of LEVs across various urban and rural landscapes.

2. **Connector compatibility:** Public charging infrastructure is often locked-in with specific vehicle connectors. For instance, a public fast-charging DC charger designed for one type of connector (e.g., GB/T) may not be accessible to EV users with CCS, Type 6, or LECCS inlets due to connector and communication incompatibility. This limits the ability of charge point operators (CPOs) to provide widespread access to fast charging for LEVs. Hence, it is proposed the concept of a universal infrastructure socket that can provide charging power in the range of 2kW to 22kW (variable DC power range of 48V to 500V) to all LEVs from a single charge point. The main idea is to untether the cable from the charger and use a detachable cable with a type 2 plug on the charger side. The EV side of the cables can have any compatible connector that meets Indian standards. The product development involves repurposing the type 2 connector for transferring power and developing the communication-capable cable with in-cable intelligence to speak the language of the relevant charging protocols. To enable communication, the cable will need to be enhanced with in-cable electronics to 'translate' the EV side communication protocol with the charger.

3. **Grid impact of multiple chargers:** The power requirement for LEVs would make it possible for LEV charging infrastructure to use the LT grid without significant augmentation. However, public charging with multiple chargers may have an adverse impact on the grid, particularly in areas where the distribution network is weak. An incremental innovation that could help augment the supply side and provide a green source for EV charging could be the use of solar PV and battery power in a DC microgrid system configuration for EV charging parks. Small pilots can be undertaken in designated parking lots of offices, starting with initial pilots in government offices, such as within the Department of Science and Technology (DST) premises.

Section 2 – High-power charging infrastructure

High power EV charging will require significant infrastructure upgrades, encompassing both power delivery infrastructure and civil infrastructure. The power delivery infrastructure includes the need for 11-33kV power connections (with each charger requiring its own separate 11 kV power connection and substation), vacuum circuit breakers (VCB), power transformers, LT C&R panels, HT and LT power cables, and bus bars. On the civil infrastructure side, this entails costs for level foundations, cable trenches, charger sheds, and control rooms.

Beyond power requirements, another critical consideration for high power charging is the choice of the charging system, or power delivery technology. Multiple configurations of high-power charging systems need to be assessed for their strategic fit and suitability.

Technology	Overview	Key barriers			Technology Interventions needed
		System	Vehicle	EVCI + Grid Integration	
Dual gun charging	Dual gun charging uses two guns simultaneously to deliver up to 500kW, doubling power delivery and halving charging time, while maintaining compatibility with existing standards and allowing for single gun use.	The lack of financial feasibility assessment of dual gun charging systems.	Integrating a dual gun inlet requires advanced Battery Management System (BMS) and sophisticated control systems to handle simultaneous connections and avoid errors. This technology is being used in e-buses with 240kW dual gun charging	Managing high power loads and effective cooling systems for dual gun chargers is complex, and simultaneous charging can impact local grid stability, necessitating careful balancing.	Testing, validation, and standardization of systems in controlled or real environment.
Pantograph based charging (Panto-Down)	Pantograph-based charging uses a fixed-mounted pantograph that lowers to connect with the EV, offering fast charging at voltage levels from 150-850V and power levels up to 600kW, with benefits including high uptime and robust design.	The lack of established Indian standards and proven concepts for pantograph systems complicates cost management and projection, with undefined CAPEX and OPEX for local conditions.	Modifications to existing e-bus and e-truck designs are needed to integrate pantograph systems, including communication enhancements, environmental protection for rails, and robust safety and performance measures.	Pantograph systems, with high power demands, can strain local grids, requiring effective grid balancing strategies to maintain stability and prevent overloads.	Assessing feasibility of cable-based system with other high power charging system Feasibility, Testing, validation, and standardization of systems in controlled or real environment

Technology	Overview	Key barriers			Technology Interventions needed
		System	Vehicle	EVCI + Grid Integration	
Catenary charging system	Catenary systems use overhead wires and pantographs on trucks to provide continuous energy, reducing battery size and extending power transfer capacity up to 500kW and voltages upto 1500V DC.	The absence of Indian standards for catenary systems and the lack of a local proof of concept complicate adoption, with uncertainties in CAPEX and OPEX potentially hindering investment.	Modifications for EV-mounted pantographs and integrated charging systems are needed, with a focus on ensuring robust communication, compatibility, and safety to prevent short circuits and misalignments.	Supply system design for High-voltage DC power systems, safety risks like short circuits and electrocution, requiring robust infrastructure design and safety measures to ensure reliable operation.	Support development of Indian standard for on-road catenary charging system *(The catenary system used in the railway has a high level of maturity, the use of the same fixed system on roads can bring new challenges related to safety, design considerations, etc.).* Controlled field trials to assess the power transfer capabilities and efficiency on the grid and the EV side Limited Product development support to OEMs for development of a Panto-up configuration

Technology	Overview	Key barriers			Technology Interventions needed
		System	Vehicle	EVCI + Grid Integration	
Inductive charging system	Inductive charging uses magnetic resonance to transfer power, offering low-power charging (up to 50kW) for stationary vehicles and dynamic charging (50kW and above) for vehicles in motion, with benefits including support for all EVs and reduced battery size.	The lack of established Indian standards for inductive charging systems and unclear financial aspects (CAPEX and OPEX) complicate development and deployment in the local context.	Robust communication and compatibility issues between inductive systems and EVs, along with potential electromagnetic interference (EMI) concerns, need to be addressed for effective operation.	The substantial power requirements of inductive charging systems may strain existing grid infrastructure, necessitating upgrades and careful management to maintain grid performance.	Support development of Indian standards for Inductive charging (WPT and dynamic WPT) Lab testing in controlled environment to assess impact and potential safety concerns from EMI Controlled field trials to assess the power transfer capabilities and efficiency on the grid and the EV side
Mega-watt charging system (MCS)	The MCS delivers up to 3.75MW of peak power with a single connector, supporting fast charging for heavy-duty vehicles like trucks and buses at voltages up to 1250V and currents up to 3000 A.	The lack of Indian standards for MCS complicates regulatory compliance, and significant grid capacity and charge management readiness assessments are required. The long-term impact on battery life also needs evaluation.	Ensuring modularity and robust communication during high-power charging, managing significant heat dissipation, and adhering to safety standards is critical. The HV architecture must handle high currents, EMI, and increased physical demands.	Establishing MCS stations in logistics hubs and ports requires substantial power capacity and grid management. Implementing charge scheduling and predictive planning is necessary to optimize usage and support commercial vehicle needs.	Feasibility assessment for MCS from the perspective of grid readiness and EV readiness

Split Charging system

Split charging system is a power management and optimization system and not a charging system but it has great relevance for high power charging.

Current charging solutions, such as integrated DC Fast chargers, combine the charging gun and power cabinet module into a single unit, providing modularity and quick deployment. However, a limitation of these solutions is the maximum of two charging guns per charger. As the power demand decreases during charging, the balance charging capacity within the charger cannot be utilized when the guns are engaged with EVs.

Split Type DC Fast EV Charger separates the charging gun and power cabinet module, housed in separate cabinets. It enables intelligent power distribution, facilitating simultaneous charging of multiple e-vehicles with equal capacity. Unlike integrated chargers, split chargers can have multiple dispenser post which can be configured with up to 12 single guns or 6 double guns with granularity of power setting at gun level ranging from 40kW to 240kW or higher for each for concurrent charging of electric vehicles from e-cars to e-buses and e-trucks.

Section 3 – Interoperability in EV charging

Interoperability refers to the seamless integration and functioning of various systems and components to achieve efficient and frictionless EV charging. It ensures that all parts of the EV charging ecosystem—vehicles, charging stations, hardware, networks, and grids—work together effectively.

Types of interoperability

- **Vehicle to charger interoperability:** This type involves ensuring hardware and communication compatibility between the EV and the EV supply equipment (EVSE). It covers the electro-mechanical connection (pin-to-socket) and the communication between the EV's and the charger's management system.
- **Charger to network interoperability:** This focuses on the communication between the charging point and the charging management system (CMS). The CMS manages charging operations, including tracking utilization, starting/stopping operations, user authentication, and payment collection. The Open Charge Point Protocol (OCPP) is commonly used for this type of interoperability.
- **Network to network interoperability:** This pertains to the ability of different CPOs and mobility service providers (MSPs) to interact and share data. Without this, EV users may need multiple subscriptions for access. The Open Charge Point Interface (OCPI) facilitates network-to-network interoperability.
- **Battery swapping interoperability:** This involves ensuring compatibility and ease of battery swapping, addressing challenges in battery-to-charger connectivity, and battery exchanges across different systems.

Key barriers and technology interventions needed

- **Standard connectors and localization support:** Many LEVs use non-standard connectors with varying designs and communication protocols, often limiting their charging capacity. These connectors, with current ratings up to 75A, contrast with standardized connectors like Type 6 and LECCS developed in India. The primary barrier is the cost difference. To address this, technology intervention is needed for product development and localization to reduce manufacturing costs of standard connectors.

- **Communication standards and cost optimization:** Communication standards for EV charging were initially tailored for four-wheelers, leading to higher costs for LEVs due to differences in charging costs and data protocol requirements. For instance, the software cost for LEV charging constitutes a higher percentage of total charging costs compared to four-wheelers. To align communication protocols with the LEV market, the following steps are suggested:

  a. Collaborate with protocol-defining organizations to streamline communication stacks.

  b. Develop simplified, cost-effective versions of existing communication protocols for LEVs.

  c. Enhance user experience and standardize interaction patterns through models like Plug & Charge.

  d. Implement certification programs to ensure compliance with established standards.

- **Interoperability among charging network operators:** India's numerous charging network operators often have proprietary apps, creating barriers for users who must subscribe to multiple services. Cooperation between operators is hindered by concerns over sharing sensitive data, such as station locations and utilization rates. The proposed solution, the Unified Energy Interface (UEI), is an indigenous decentralized network akin to the Unified Payment Interface (UPI). UEI enables seamless EV charging access across different operators without requiring multiple apps, promoting greater interoperability and access by utilizing the BECKN protocol for digital economy integration.

01

LEV CHARGING INFRASTRUCTURE

LEV CHARGING IN INDIA must cater to LEVs, which primarily include 2Ws, 3Ws, and small 4Ws, representing over 90% of the total EV population. For e-2Ws, the maximum battery pack typically reaches about 5kWh (100Ah), while for e-3Ws, it can be up to 11kWh (210Ah), constrained by the form factor and available space. Given current battery chemistries, it is projected that LEV battery capacity will not exceed 15kWh in the short- to medium- term due to space and pricing constraints. Table 1.1 provides an overview of existing LEV battery configurations.

Table 1.1: Existing LEV ecosystem

Vehicle	Battery (Fixed)	Battery pack size (Ah)	Max C rating (Charging)
2W	48V 60V 72V 96V	60 Ah 80 Ah	1C
3W	48V 72V 96V	160 Ah 200 Ah	0.5 – 1 C

Most LEVs in the current ecosystem operate with battery voltages in the 48V - 72V range. For a 48V system and a 210Ah battery pack with a 0.5C realistic charging rate, the maximum power requirement is around 6kW. Similarly, for LEV batteries in the 96V - 120V range, the maximum power requirement typically does not exceed 12kW. Even for a futuristic 120V system with a 125A charging current, the power need would generally be capped at 15kW (250Wh/min). Table 1.2. provides an overview of the existing LEV system and charging requirements. The LEV performance chart depicts the power requirement for charging different classes of LEVs.

Table 1.2: Charging requirement for different LEVs

Peak charging power per min (Wh/min)	Vehicle Wh/Km	kWh/100 kms	Range gain per minute (km/min)	Vehicle class	Range in 30 minutes of charging	Time for 100 kms range (min)
250	20	2	12.5	Low speed e-bike	375	8
250	30	3	8.3	Personal 2W	250	12
250	40	4	6.3		188	16
250	50	5	5	High performance 2W	150	20
250	60	6	4.2		125	24
250	70	7	3.6	Low speed e-rickshaw	107	28
250	80	8	3.1		94	32

Peak charging power per min (Wh/min)	Vehicle Wh/Km	kWh/100 kms	Range gain per minute (km/min)	Vehicle class	Range in 30 minutes of charging	Time for 100 kms range (min)
250	90	9	2.8	High speed rickshaw	83	36
250	100	10	2.5		75	40
250	110	11	2.3	Commercial Cargo 3W	68	44
250	120	12	2.1		63	48
250	130	13	1.9	High Performance Utility 3W	58	53
250	140	14	1.8		54	56
250	150	15	1.7	Large electric e-freight	50	59

1.1. LEV charging standards

LEV charging in India is regulated by specific standards for both AC and DC charging. The IS 17017-22-1 standard governs AC charging for LEVs, allowing up to 240V AC and 16A, with provisions for safety, functionality, and communication, suitable for single-phase connections. For DC charging, IS-17017 Part-25 covers equipment for up to 120V DC and 100A, while IS-17017 Part-2 Section-6 specifies connectors for the same voltage and current. These standards ensure proper control and safety in DC systems. Combined charging is addressed by IS-17017 Part-2 Section-7, which supports AC up to 7kW and DC up to 12kW through a single connector. IS-17017 Part-31, is released and specifies combined AC and DC charging up to 240V AC and 32A or 120V DC and 100A through a unified connector.

1.1.1. AC charging

LEV AC EVSE (Level-1: < 7kW): The IS 17017-22-1 standard was developed specifically to support a low-cost charge point for LEVs. This standard applies to basic conductive AC charging options for LEVs with a rated supply voltage of 240V AC and current up to 16A AC. It covers requirements for functionality, environmental aspects, energy measurement, and mechanical and electrical safety considerations, and describes communication provisions. In terms of load requirement, it is equivalent to a single-phase connection.

Table 1.3: LEV AC Charging Point Standards

Power level 1	Charging device	EV-EVSE communication	Charge point plug/socket	Vehicle inlet/ connector
Up to 3.3kW	IS-17017-22-1	Bluetooth low energy (BLE)	IS-60309	As per the EV manufacturer

1.1.2. DC charging (Level 1 and 2 DC charging)

LEV DC charging: IS-17017 Part-25 (DC EV supply equipment for LEV) provides the requirements for the control and communication between DC EV supply equipment and an LEV to supply up to 120V DC and current up to 100A DC. This standard covers characteristics and operating conditions, specification of the connection between the DC charger and EV, and requirements for electrical safety.

DC connectors and vehicle inlet for LEV: IS-17017 Part-2 Section-6 specifies requirements for DC connectors and vehicle inlets for EV charging systems with control means and rated operating voltage up to 120V DC and rated current up to 100A.

Table 1.4: LEV DC charging point standards

Power level 1	Charging device EV-EVSE communication	Charge point plug/ socket	Vehicle inlet/ connector
Up to 12kW	IS-17017-25 [CAN]	Not Applicable	IS-17017-2-6

1.1.3. Combined AC and DC charging (AC up to 7 kW and DC up to 12 kW)

Light Electric Combined Charging System (LECCS): IS-17017 Part-2 Section-7 specifies the LECCS for vehicle inlet and connector, supporting charging of AC up to 7kW and DC up to 12kW through a single connector (like CCS2 for cars).

Combined AC and DC charging: IS-17017 Part-31 provides the requirements for control and communication between EV supply equipment and the EV to supply up to 120V DC and current up to 100 A DC, or up to 240V AC and 32A AC through a single connector.

Table 1.5: LEV Charging Point Standards

Power level 1	Charging device EV-EVSE communication	Charge point plug/ socket	Vehicle inlet/ connector
DC up to 12kW	IS-17017-31 [CAN]	Not applicable	IS-17017-2-7
AC up to 7kW	IS-17017-31 [CAN]	Not applicable	IS-17017-2-7

1.2. Challenges and recommendations in the LEV charging

1.2.1. Indigenization of DC charging technology

Many LEV OEMs avoid integrating on-board chargers due to challenges in packaging and heat dissipation, instead opting for off-board DC portable chargers, typically under 1kW. These portable chargers convert AC from mains to DC for the vehicle, offering ease of use and reducing vehicle complexity. However, their power transfer is limited compared to public DC fast chargers, which provide greater power and faster charging rates.

Commercial EV operators often bypass portable chargers in favor of DC fast chargers for quicker charging. While DC charging can be adapted for various power levels depending on the charge point's capacity, there remains a heavy reliance on imported DC chargers.

Indigenizing DC charging technology, particularly by developing smaller, modular power devices, could significantly impact the LEV market. Embracing domestic manufacturing of devices using SiC or GaN technologies, known for their high-temperature tolerance, could lead to more compact and efficient EV chargers, supporting widespread and flexible destination charging solutions.

1.2.1.1. Recommendations

To support large-scale DC charging, a slightly downsized (12kW) public DC charger can meet this requirement provided it can be indigenously developed (100% indigenization) leading to large reduction cost of the unit and the cost of infrastructure. Developing indigenous DC chargers of up to 12kW for large scale deployment could be the key to enabling a widespread LEV charging infrastructure.

1.2.2. Lock-in of charging infrastructure limits public charging solutions

Proprietary charging hardware and connectors used by many 2W and 3W manufacturers create significant challenges for both EV users and CPOs. The diversity in socket and vehicle inlet combinations, along with varying communication standards, hinders the widespread adoption of fast charging solutions. This issue, related to the standardization of LEV connectors, is further explored in Section 3 on interoperability.

A major concern is the lock-in effect of public charging infrastructure. Fast-charging DC stations designed for specific connectors, such as GB/T, often do not support other types like CCS or Type 6 due to incompatibilities in connectors and communication protocols. This restricts the ability of CPOs to offer broad and efficient fast charging options for LEVs, limiting their accessibility and convenience.

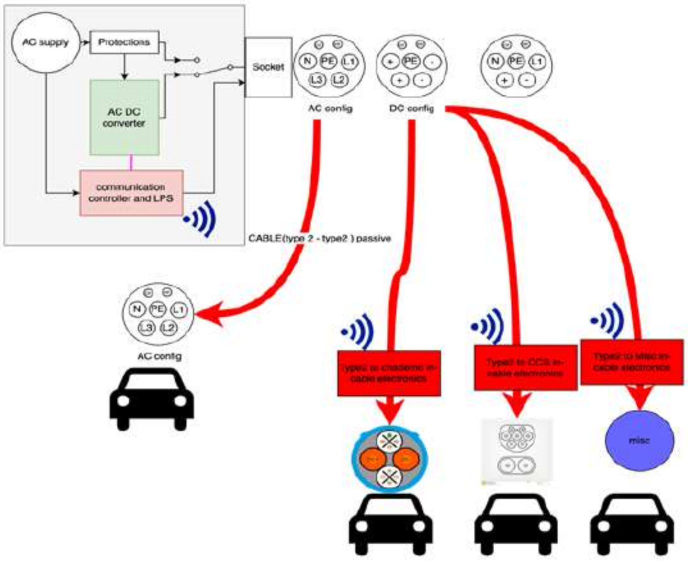
1.2.2.1. Destination charging with universal infrastructure socket

The development of a Universal Socket for destination charging is crucial to address the diverse needs of LEVs in India. The universal infrastructure socket should support charging power ranging from 2kW to 22kW, with a variable DC power range of 48V to 500V. By employing a detachable cable system with a Type 2 plug on the charger side, this solution allows for compatibility with various connectors on the EV side, including CCS, CHAdeMO, GB/T, and Light EV DC systems.

The proposed universal charging system involves repurposing the Type 2 connector for power transfer and developing an intelligent cable with in-cable electronics. These electronics would facilitate communication between the EV and the charger, translating different charging protocols to ensure interoperability. This system aims to simplify the charging infrastructure, making it more adaptable and user-friendly.

Destination charging would be supported through standard low-tension (LT) connections (50kW) provided by distribution utilities at secure and managed locations such as apartment complexes, office buildings, and shopping districts. This approach aligns with government guidelines on EV charging infrastructure, promoting job creation and small business opportunities while enhancing accessibility to EV charging solutions.

Figure 1.1: Schematic of the proposed Universal Destination Charger



Basic design concept of the destination Park-bay charger

The Universal Infrastructure Socket concept aims to enhance destination charging for LEVs. This system will deliver charging power ranging from 2kW to 22kW, accommodating both AC and DC power in the 48V to 500V range. The Universal Destination Charging Socket will utilize the Type-2 (Mennekes) connector, renowned for its compact size, durability, and global adoption. It is anticipated that destination charging will predominantly use DC power.

The design features a detachable cable system with a Type 2 plug on the charger side, allowing for flexibility in cable connections on the EV side. This approach supports various compatible connectors, such as Type 6, Type 7, CCS, and GB/T, meeting Indian standards. This design aims to streamline the charging process, improving convenience and compatibility for LEV users.

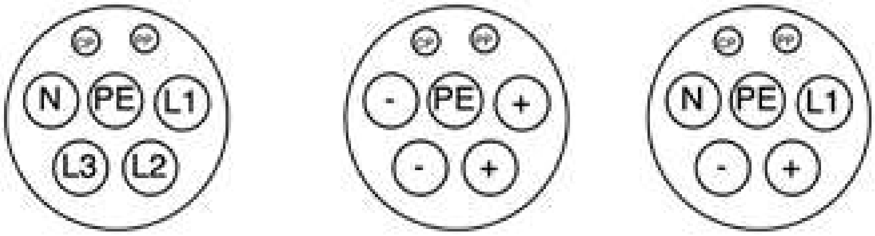
<u>Repurposing Type 2 socket:</u>

The Type 2 socket, featuring five larger pins (N, PE, L1, L2, and L3) for power and two smaller pins (CP and PP) for control, is designed for AC charging as defined in IEC 61851-1 and IS 17017-1. These control pins, originally intended for AC voltage capacity, can be repurposed for powering in-cable electronics in DC charging scenarios.

For AC configurations, such as a passive probe setup (Type 2 to Type 2), wireless communication is generally unnecessary. In contrast, DC charging requires wireless communication and in-cable electronics to manage and control the charging process effectively.

Operational overview

Figure 1.2: Universal Socket Configuration (1) AC; (2) DC; (3) AC and DC



In-cable electronics

To facilitate communication in the charging system, the in-cable electronics will incorporate two primary components: a charging controller and a BLE transceiver. This setup enables wireless communication between the charger and the vehicle. The choice of wireless communication technology, such as Bluetooth, will require validation and testing.

Operational flow

The charger's internal contactor controls the switch between AC and DC modes. In AC configuration, the vehicle connects directly to the infrastructure socket. For DC charging, the charger includes an AC/DC converter and a communication controller to provide DC output to the socket. In this configuration, pins L1 and L2 will be assigned as positive, while N and L3 will be negative, as defined in the DD configuration.

When the infrastructure socket connects to an EV plug, such as a CCS plug, the pin assignments switch: N and L3 become negative, while L1 and L2 become positive. These connections are made through the cable, and the protective earth from the infrastructure socket is linked directly to the protective earth in the CCS plug. The CP pin of the infrastructure socket connects through the in-cable electronics. The operational setup for a CCS-compatible cable is illustrated in the accompanying diagram.

Figure 1.3: Schematic of Cable Configuration (CCS)

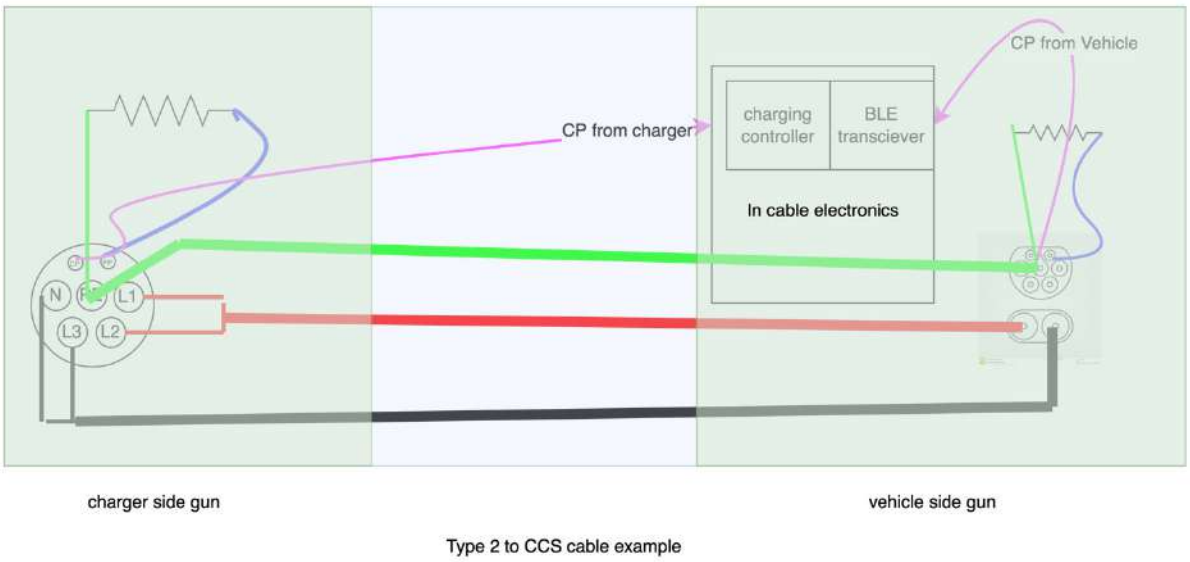


Figure 1.4: Details of Connecting Cable and Communication Module

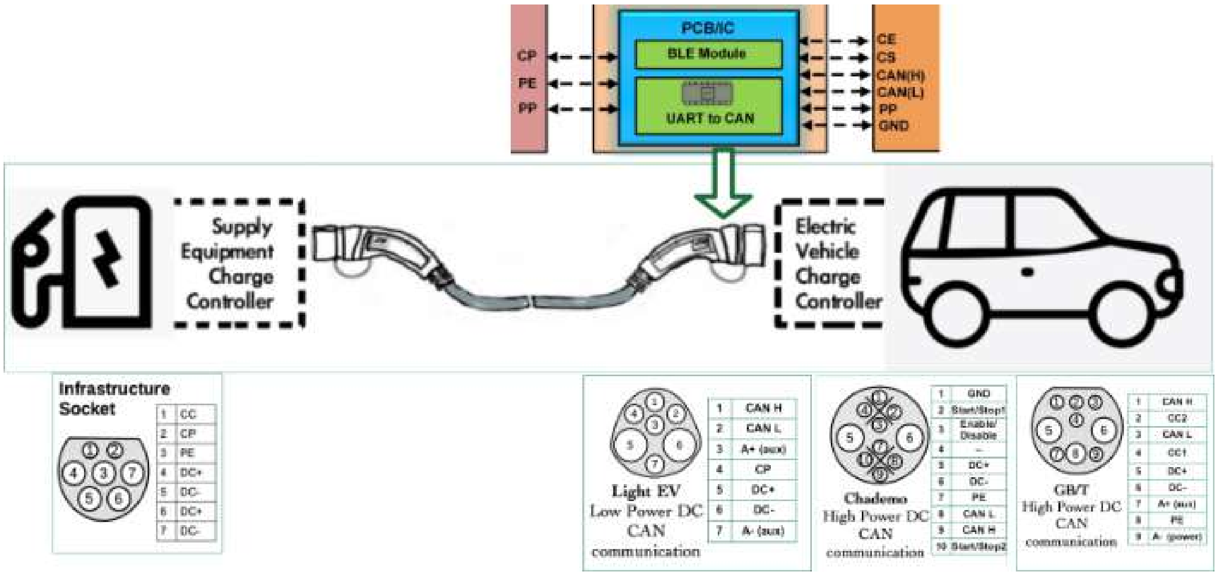
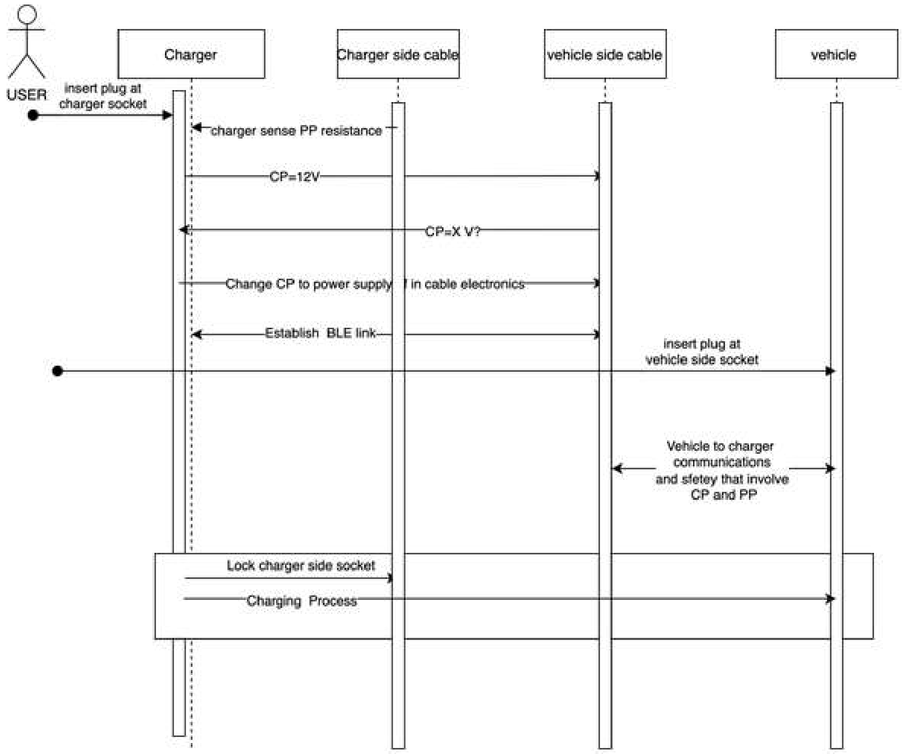


Figure 1.5: Operational flow



1.2.3. Microgrids

An effective strategy to enhance the supply side and introduce a green source for EV charging is the deployment of solar PV and battery power within a DC microgrid system for EV charging parks. This approach allows for scalable, cost-effective solutions with minimal impact on the grid. By integrating 'smart plugs' or a Destination Parking Management System, charging schedules can be optimized across parking bays, enabling the microgrid to operate largely independently from the grid.

Furthermore, combining renewable energy sources with park bay charging infrastructure supports the accelerated deployment of LEV Battery as a Service (BaaS) exchange or swap stations. These stations, when co-located with EV parking and charging facilities, can become operational swiftly, even before the LEV market reaches substantial scale.

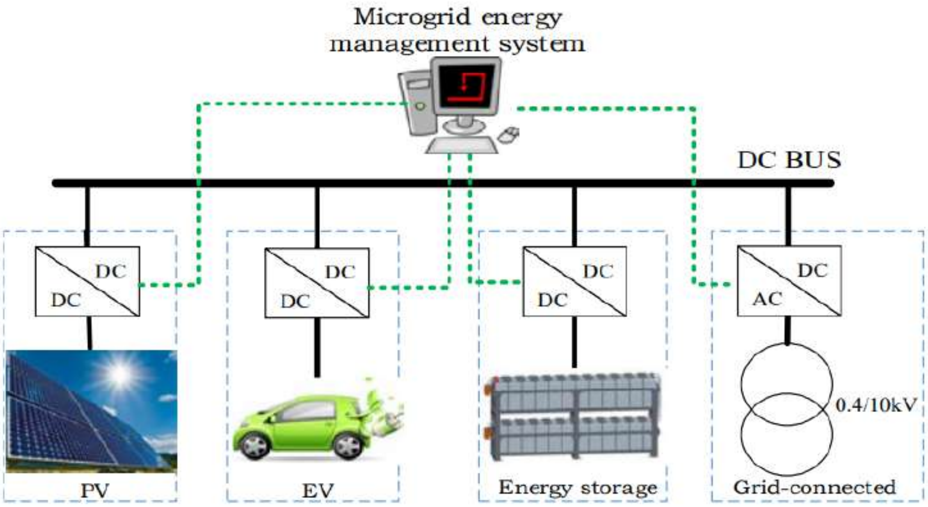
To implement this innovation, it is proposed to initiate small-scale pilot projects in designated parking lots, starting with government office premises. This will help demonstrate the feasibility and benefits of the proposed system in a controlled environment.

Solar PV and storage-based EV charging micro-grid

A solar PV-based DC microgrid for EV charging integrates various components to optimize energy management and efficiency.

A DC microgrid is mainly composed of PV system, EV charging device, battery energy storage system, grid connected system, and microgrid energy management system, as shown below:

Figure 1.6: Simple schematic of Solar PV-battery- based DC microgrid



Structure of the DC microgrid

- **PV system:** Comprising PV modules and a DC/DC converter operating with MPPT (Maximum Power Point Tracking), the PV system generates power influenced by solar irradiation and environmental conditions.
- **DC/DC EV charger:** This includes the DC charger and the EV battery. The charger's output power and current are controllable, with charging time dependent on the power capacity and current.
- **Energy storage system:** Featuring lithium-ion batteries and a DC/DC converter, this system manages load shifting, energy storage, and power fluctuation smoothing.
- **Microgrid energy management system:** This system monitors and controls the operation of the microgrid's components. It optimizes energy use by regulating EV charging power from the PV system, energy storage, or the grid, balancing overall microgrid performance.
- **Grid-connected system:** Comprising a bidirectional AC/DC inverter and a distribution transformer, this system facilitates energy transfer between the grid and the microgrid, maintaining DC bus voltage stability.

Operational modes

The microgrid operates in six modes to optimize energy flow:

- **Mode-1 (PV to EV):** When PV power meets EV demand, the EV charges directly from the PV system without grid or energy storage involvement.
- **Mode-2 (ESS to EV):** If PV power is unavailable but the energy storage system (ESS) has enough energy, it will supply the EV, reducing grid reliance.
- **Mode-3 (Grid to EV):** If both PV and ESS fail to provide power, the EV charges directly from the grid.
- **Mode-4 (PV to ESS):** When there's no EV to charge and PV power is less than or equal to the ESS's required state of charge (SOC), all PV power is directed to the ESS to store energy for future use.
- **Mode-5 (PV to grid):** If the ESS is fully charged and PV power is available, excess energy is sold to the local grid as per regulations.
- **Mode-6 (ESS to grid):** When PV power is insufficient to meet AC load demands, the ESS supplies power to the grid.

Table 1.6. Charging Scenarios

S No.	Scenario	Condition	Operation modes
1	No load condition	PV_Pwr is available but EV_Dmd is zero	Mode 4,5
2	Over load condition	EV_Dmd is greater than the PV_Pwr	Mode 1,2,3
3	Under load condition	EV_Dmd is less than PV_Pwr	Mode 1,4,5
4	AC load demand condition	Ld_Dmd (Grid) must be fulfilled without any interruption	Mode 5,6

02

HIGH-POWER EV CHARGING

HIGH POWER CHARGING is essential for e-buses and heavy-duty electric trucks (HDETs), with varying requirements based on the type of vehicle and usage patterns. E-buses require different charging strategies depending on their route and battery capacity: city buses might need overnight charging, while long-distance buses may require a combination of destination and fast opportunity charging. Conversely, the freight sector demands rapid charging solutions to maximize uptime and capacity.

Current e-bus chargers offer power outputs up to 180kW, adequate for recharging during layovers. However, high power chargers need to support outputs of 450kW or more. The infrastructure for such high-power charging includes significant upgrades to both power delivery and civil infrastructure. This involves setting up 11-33kV power connections, HT breakers, transformers, and extensive civil works like foundations, cable trenches, and control rooms.

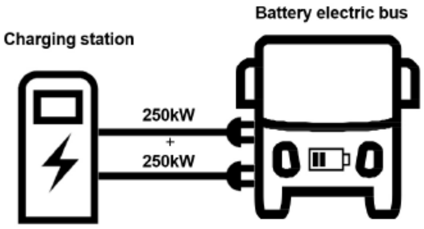
The selection of high-power charging systems is also crucial and varies across several technologies, each with distinct configurations and advantages. These include:

» **Dual Gun Charging:** Utilizes two separate charging guns
» **Pantograph Down Charging:** Features an overhead fixed pantograph
» **Catenary Charging:** Employs overhead fixed lines with a vehicle-mounted pantograph
» **Inductive Charging:** Includes both stationary and dynamic forms of wireless charging
» **Mega-watt Charging Stations:** Supports extremely high-power outputs
» **Split Charging System:** Not a charging configuration but a power management solution for high power applications

2.1. Dual-gun charging technology

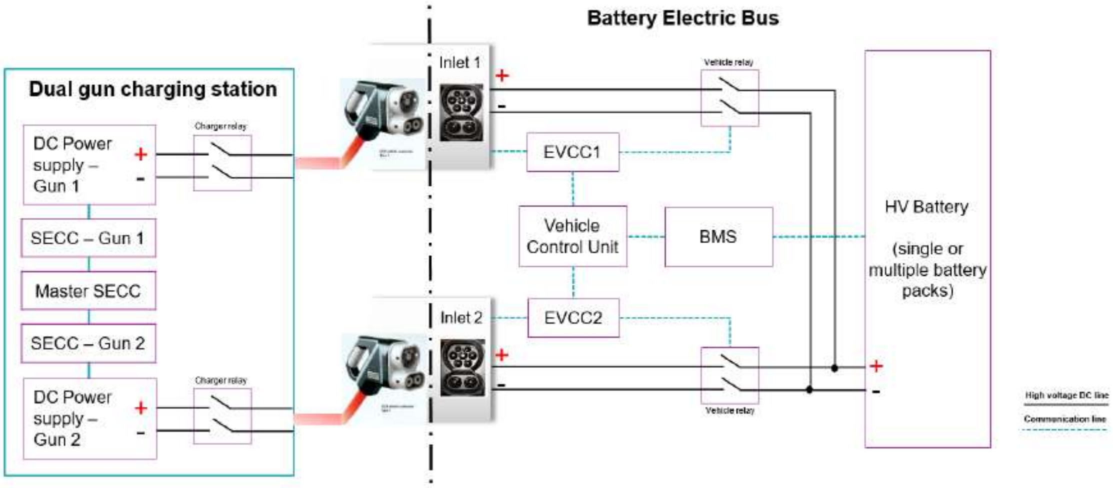
Dual Gun Charging technology offers a solution for high-power EV charging, accommodating power delivery requirements up to 500kW. Unlike CCS single gun chargers, which provide power up to 250kW or 350kW, dual gun chargers mitigate the need for costly infrastructure upgrades by delivering increased power through two separate outlets. This configuration enables faster charging by effectively doubling the power delivery rate, thereby halving the charging time.

Figure 2.1: Dual Gun Charging



The details of Dual Gun Charging station is shown in figure 2.2, the overall charging infrastructure and charging components.

Figure 2.2: Architecture of Dual Gun Charging (Image Source: Bureau of Indian Standards - BIS)



The infrastructure for dual gun charging is similar to that of single gun systems but includes two Supply Equipment Communication Controllers (SECCs) managed by a master communication controller. This setup allows for synchronized operation and power delivery from both outlets. Users can select between single gun or dual gun modes via a display on the charger, with the master SECC coordinating the appropriate power delivery mode.

It is crucial for users to ensure that both guns used in the dual gun system are connected to the same charging station to avoid operational issues. Connecting guns from different stations may result in errors or warnings, depending on the design specifications set by the OEMs.

Key benefits of Dual Gun Charging

1. **Enhanced efficiency**: Dual Gun Charging provides faster and more efficient charging, making it a viable solution for permanent e-bus infrastructure. This capability supports rapid recharging and operational efficiency.

2. **Cost reduction:** By enabling per-trip charging, dual gun systems reduce the need for large battery capacities, thereby lowering the overall cost of e-buses. With e-buses weighing approximately 3 tonnes, where high-voltage batteries account for about 30% of the weight, reducing battery size directly impacts cost and weight.

3. **High power capability:** Capable of delivering up to 500kW, dual gun charging eliminates the need for expensive liquid-cooled cables by distributing the charging current across two paths. Existing cables and designs from single gun charging stations can be reused, further reducing infrastructure costs.

4. **Compatibility and reusability:** Dual Gun Chargers operate synchronously with two cable connections, utilizing the same communication protocols and components as single gun systems. This compatibility allows for the reuse of existing components and wiring, avoiding the need for new communication controllers and components.

5. **Standardization:** Dual Gun Chargers can leverage established standards like CCS or GB/T, which are widely used and tested globally. This standardization ensures reliability and facilitates integration into existing charging networks.

6. **Fallback option:** In the event of a failure, dual gun chargers can revert to single gun charging without leaving the vehicle's high-voltage battery uncharged, ensuring continuous operation and reliability.

2.1.1. Standards for dual-gun charging

Dual-gun charging technology, which allows for efficient high-power delivery, has been integrated by some Indian OEMs using the CCS2 protocol, supporting up to 180kW. Draft Indian standards for this technology have been developed under the PSA-DST consultative group and were shared with the BIS-ETD51 Sectional Committee in early 2022 for further review and release.

The key standard for dual gun charging is IS-17017-23-2, which outlines requirements for DC charging stations with power outputs ranging from 50kW to 200kW. Additionally, IS 17017-3-1, the main document, specifies the electrical interfaces, power flow parameters, communication protocols, and safety systems. For communication, the control pilot is used once the vehicle is connected to the charger, while wireless communication - specifically IEEE 802.11n - is employed to pair the vehicle with the charging infrastructure. Testing requirements for these systems are also defined in the standards.

2.1.2. Challenges

System side challenges: One of the primary challenges is the lack of available cost data for both CAPEX and OPEX under Indian conditions. This information is crucial for assessing the financial feasibility and sustainability of implementing dual gun charging systems in the local market.

- **Vehicle side challenges:** On the vehicle side, integrating a Dual Gun inlet presents significant challenges. The reconfiguration of BMS to accommodate dual gun charging requires advanced intelligence. Vehicles must handle dual guns through a master-slave concept, ensuring that charging is only authorized if both connectors are from the same charging station and that any asynchronous operation is avoided. This necessitates sophisticated control systems to manage simultaneous connections and prevent errors.

- **Infrastructure and grid integration challenges:** From an infrastructure and grid integration perspective, managing power and cooling systems is complex. Dual Gun Chargers, which can deliver up to 400kW per bus, require effective liquid cooling for cables to handle the high-power loads. Additionally, the simultaneous charging of multiple buses can significantly impact local grid stability, necessitating careful grid balancing to prevent disruptions.

2.1.3. Recommendations

- **Assess feasibility of Cable-Based Systems:** Evaluate the feasibility of integrating cable-based systems with other high-power charging technologies.
- **Testing, validation, and standardization:** Conduct comprehensive testing and validation of Dual Gun Charging systems in both controlled environments and real-world conditions.

2.2. Automated pantograph charging technology

Pantograph technology, long established in railways, is increasingly being adapted for EV charging, particularly for depot and opportunity charging applications. Capable of delivering up to 600kW, pantograph systems substantially reduce charging times. The effective power transfer, however, depends on the BMS and battery capacity. For instance, a 300kWh battery pack at a 1C rating typically supports up to 300kW of charging power.

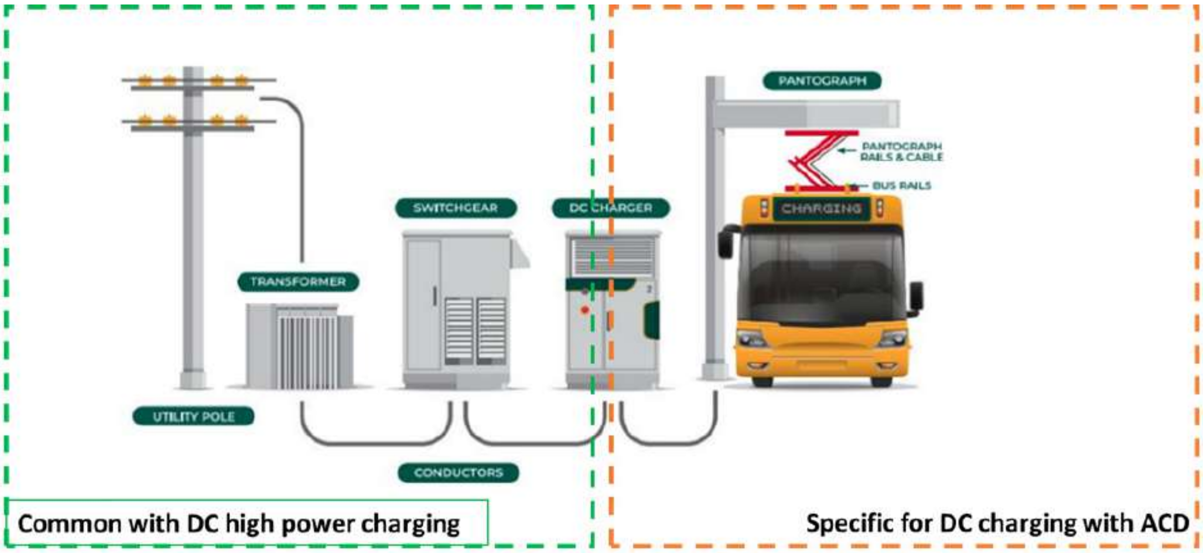
Recent implementations highlight the potential of pantograph systems. The Pantograph solution for India offers a safe and reliable automated connection, available in voltage levels ranging from 150-850V and power levels of 100kW, 150kW, 300kW, 450kW, and 600kW. This technology provides several key benefits:

» **Rapid charging:** The pantograph system supports fast charging across a wide range of power levels, optimizing charging times for various applications.

» **High uptime:** Its robust design ensures reliability and durability, with remote diagnostics and management tools facilitating efficient operation and maintenance.

» **Extended lifespan:** While traditional connectors support up to 10,000 charging cycles, pantograph systems can endure up to 30,000 cycles, making t hem a more durable option.

Figure 2.3: Architecture of Pantograph Charging (Image Source: King County Metro - Seattle)



Opportunity charging enables e-buses or e-trucks to receive a top-up charge through a pantograph system in just a few minutes while stopped at a bus stop. This approach leverages short dwell times to efficiently recharge batteries, transforming regular bus or truck stops into functional charging points. By integrating these stops as charging stations, the system provides a complete interface between the energy grid and the vehicle. With energy transfer capabilities reaching up to 600kW, opportunity charging significantly reduces both the duration of charging and the frequency of charging stops.

One of the key advantages of opportunity charging is that it eliminates the need for large, expensive battery packs on board. Smaller batteries reduce vehicle weight, increase passenger capacity, and lower overall costs, enhancing the efficiency and affordability of electric buses. This allows manufacturers to design lighter, more energy-efficient buses at a reduced cost.

The primary goal of pantograph charging is to establish interoperable charging systems with common infrastructure along vehicle routes. This means that any EV equipped with pantograph technology can be charged at any available e-bus pantograph charging station.

Compared to traditional cable-based charging systems, pantograph solutions offer enhanced safety, reliability, and automation. They support charging multiple buses with various voltage levels and power ratings. Transitioning from cable-based systems to pantograph technology requires installing compatible bus bars or rails on e-buses, additional components for wireless communication, and modifications to junction boxes. *Note: Pantograph fitted Ashok Leyland Bus is running on trials at IIT Madras. It is a Tosa based charging system in collaboration with Hitachi Energy (earlier known as ABB Power Products and Systems) and Ashok Leyland. Also, ARAI, Pune is in process of doing R&D project to develop India specific pantograph system. This project is sponsored by IIT Madras (COZET).*

2.2.1. Standards for automatic pantograph

The Bureau of Indian Standards (BIS) Committee referenced SAE standards in the drafting of the Indian Standard for Automated Connection Devices, specifically for e-Bus pantographs. The SAE standards presented three options for pantograph systems:

- » **Infrastructure-Mounted Cross Rail Connection Pantograph (Panto Down)**
- » **Vehicle-Mounted Pantograph (Panto Up)**
- » **Pin and Socket Connection**

After thorough deliberation, the BIS Committee chose the **Infrastructure-Mounted Pantograph (Panto Down)** as the most suitable option for India. This decision was based on its alignment with local needs and conditions.

Following draft standards for pantograph charging system are under consideration:

- **IS-17017-3-1:** This standard will outline the general requirements for automated pantograph charging stations, covering the overall infrastructure and operational aspects.
- **IS 17017-3-2:** This document will specify the requirements for infrastructure-mounted cross rail connections, including connecti on arrangements, components, and alignment details.

2.2.2. Challenges

The adoption of pantograph technology for EV charging presents several challenges across different aspects of its implementation.

- **System side challenge:** A significant challenge is the lack of established Indian standards and the absence of a proven concept under Indian conditions. Cost-related issues also pose a challenge, as the CAPEX and OPEX for pantograph systems are not well-defined for Indian contexts, making cost management and projection difficult.
- **Vehicle side challenge:** Existing e-bus and e-truck designs need substantial modifications to accommodate pantograph systems. This includes incorporating Wi-Fi communication devices, relocating battery systems, and adjusting HVAC and cooling systems to fit the DC rails. Furthermore, the rails must be protected from environmental factors such as heat, dust, and humidity. Communication robustness between the EVSE and the charger is critical, requiring reliable operation despite potential movements or misalignments. The geometric and material properties of Automated Connection Devices (ACD) and their counterparts must be optimized to ensure effective performance. Safety considerations related to potential short circuits

and the overall system's cost, operational economics, and efficiency must also be addressed.

- **Infrastructure and grid integration challenge:** One major concern is grid balancing. Pantograph systems, which can demand up to 450kW per bus, may impact the local grid when multiple buses are charged simultaneously. This necessitates careful management and grid balancing strategies to prevent overloads and maintain grid stability.

2.2.3. Recommendations

- **Feasibility Study:** Conduct a comprehensive feasibility study comparing the Panto-down system with traditional cable-based systems.
- **Product development support:** Provide targeted product development support to CPOs and Original OEMs to facilitate the development of infrastructure components required for pantograph systems.
- **Controlled field trials:** Implement controlled field trials to evaluate the power transfer capabilities and efficiency of pantograph systems. These trials should include assessments of grid impact and explore the integration of ESS, Vehicle-to-Grid (V2G) technologies, and Energy-as-a-Service (EaaS) or Charging-as-a-Service (CaaS) business models.

2.3. Catenary charging system

Catenary systems for trucks utilize two overhead wires strung along designated routes, with battery electric trucks equipped with a pantograph - a mechanical device mounted on the vehicle's roof - drawing current from these wires. This system enables continuous charging while the truck is in motion by maintaining contact with the overhead catenary wires.

Figure 2.4. Catenary Charging System (Image Source: Clean Energy Wire)

The pantograph, which consists of spring-loaded arms, contacts the catenary wires to facilitate ongoing power transfer. This continuous charging capability helps reduce the battery size needed for the truck, thereby extending its range and improving transit times. The system can deliver up to 500kW of power at voltages up to 1500V DC.

Additionally, catenary charging systems can leverage the extensive experience and cost efficiencies associated with the infrastructure used by Indian Railways for pantographs and overhead lines. This existing infrastructure provides a solid foundation for implementing catenary charging technology, potentially reducing costs and accelerating deployment.

Catenary charging systems offer several key advantages over conventional stop-and-go charging methods. By eliminating lengthy downtime at charging stations, catenary systems significantly enhance operational efficiency and driver productivity.

Key benefits include:

- **Ideal for long-distance transport corridors:** The overhead catenary system is particularly well-suited for long-distance transport corridors and is noted for its low total cost of ownership (TCO) when deployed at scale.
- **Integration of renewable energy:** For long freight corridors, power can be supplied from dedicated points, facilitating large-scale integration of renewable energy sources.
- **Powering wayside stations:** The catenary system can also supply power to wayside stations, eliminating the need for separate power arrangements.
- **Minimal traffic disruption:** Overhead lines can be installed without significantly disrupting highway traffic, offering a less intrusive alternative compared to in-road wireless charging systems.

2.3.2. Challenges

- **System side challenges:** One major challenge is the absence of an Indian standard specifically for catenary systems, which complicates the adoption and implementation of this technology. Additionally, there is a lack of proof of concept in Indian conditions, making it difficult to gauge its effectiveness and reliability in the local context. Cost considerations, including both CAPEX and OPEX, are also uncertain, which can hinder investment decisions and planning.
- **Vehicle side challenges:** Modifications to vehicle designs are necessary to accommodate the installation of EV-mounted pantographs and integrated charging management systems. Ensuring robust communication during charging is crucial to prevent disturbances caused by vehicle movements or misalignments. Compatibility between the charging system, the charging receiver, the vehicle, and the BMS must be carefully managed. Safety considerations, particularly concerning potential short circuits, are also critical.

- **Charging infrastructure and grid integration challenges:** Designing the supply system for high-voltage DC power presents its own set of challenges, including ensuring the safety of the infrastructure against short circuits and electrocution risks. Proper safety measures and infrastructure design are essential to mitigate these risks and ensure reliable operation.

2.3.3. Recommendations

» **Development of Indian standards**: Support the creation of Indian standards for on-road catenary charging systems. Although the catenary system used in railways is well-established, adapting it for road use involves new challenges related to safety and design considerations. Establishing standards will address these issues and facilitate smoother implementation.

» **Controlled field trials**: Conduct controlled field trials to evaluate the power transfer capabilities and efficiency of the catenary charging system on both the grid and the EV side.

» **Product development support**: Provide limited product development support to OEMs for the development of pantograph-up configurations.

2.4. Inductive charging

Inductive charging uses magnetic resonance coupling for power transfer, offering two distinct capabilities tailored to different charging needs:

- **Low-power charging (up to 50kW):** This type is suited for overnight or depot charging of buses and trucks, providing a steady, slow flow of energy. It functions like dedicated overnight power stations that quietly recharge batteries while vehicles are not in use.

- **Dynamic charging (50kW and above):** This system facilitates en-route charging, allowing vehicles to charge while in motion or at designated stops. It is particularly useful for buses and specific truck routes, enabling them to top up their batteries on the move through electrified sections of highways or specialized charging zones.

These capabilities allow inductive charging systems to cater to various operational scenarios, from long-term depot charging to dynamic en-route replenishment.

Inductive charging employs magnetic resonance coupling to transfer power wirelessly. The system includes inductive loops embedded in the road, which generate a magnetic field to supply energy to electric vehicles. It consists of a primary coil installed in the road, connected to the power grid, and a secondary coil fitted beneath the EV.

In dynamic wireless inductive charging, charging pads embedded in the road feature insulated copper coils linked to the power grid. As an EV equipped with a receiving coil approaches a charging pad, an oscillating magnetic field is created in the primary coil.

This magnetic field induces a current in the secondary coil on the vehicle, which then charges its battery.

Key benefits include:

- **Reduced battery size:** The ability to charge while in motion allows for a downsized battery pack, which reduces vehicle weight and cost. This can be particularly advantageous for regular bus routes, where frequent charging is feasible.
- **Operational efficiency:** Inductive charging can be integrated into highways or designated lanes. When an electric bus's battery runs low, it can switch to a recharging lane to top up its power and then return to the regular lane once fully charged.
- **Seamless integration:** The system can be effectively integrated with highway infrastructure, allowing for continuous operation without the need for large, stationary charging stations.

Inductive charging offers a practical solution for en-route energy replenishment, contributing to operational efficiency and reducing the need for large battery packs.

2.4.1. Standards for inductive charging

Indian standards for Inductive charging have not been defined. However, SAE standard SAE J2954/2 is published for stationary inductive charging. For dynamic WPT (wireless power transfer), the standard SAE RP J2954/3 (For Dynamic WPT) is under preparation.

2.4.2. Challenges

- **System side challenges:** The absence of an established Indian standard for inductive charging system poses a significant hurdle, complicating the development and deployment of these technologies within the local context. Additionally, there is a lack of proof of concept for inductive charging systems under Indian conditions. The financial aspects also remain unclear, as the capital CAPEX and OPEX associated with these systems are not well-documented in the Indian market, making it difficult to assess their financial feasibility.
- **Vehicle side challenges:** Ensuring robust communication between the inductive charging system and the EV during operation is crucial. Movements and misalignments of the vehicle can disrupt this communication, potentially impacting the efficiency of the charging process. Moreover, compatibility issues between the inductive charging system and the vehicle's charging receiver, as well as its BMS, need to be addressed to prevent operational problems. There is also limited evidence on the potential impact of EMI generated by inductive charging systems on people and animals, raising concerns about health and safety.
- **Infrastructure and grid integration challenges:** Inductive charging systems require substantial grid power, which can strain existing power infrastructure and necessitate significant upgrades. Furthermore, the efficiency of power transfer in these systems

can affect overall grid performance, requiring careful management to mitigate any potential impacts on the grid.

2.4.3. Recommendations

To advance inductive charging technology, several key actions are recommended:

- **Development of Indian standards:** Support the development of Indian standards for both wireless power transfer (WPT) and dynamic wireless power transfer (WPT) systems.
- **Lab Testing for EMI Impact:** Conduct laboratory testing in a controlled environment to assess the potential impact of EMI generated by inductive charging systems.
- **Controlled field trials:** Implement controlled field trials to evaluate the power transfer capabilities and efficiency of inductive charging systems on both the grid and the electric EV side.

2.5. Megawatt charging station (MCS)

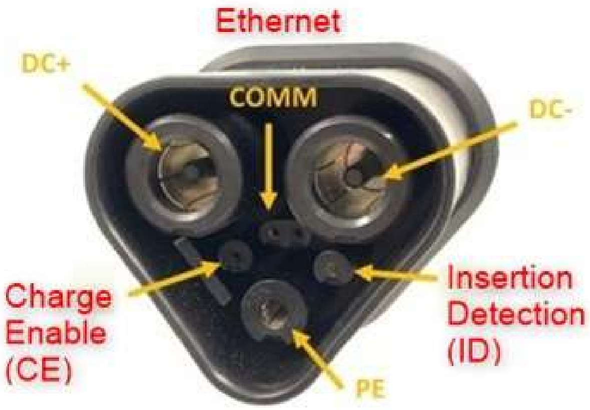
The MCS represents a significant advancement in charging technology, specifically designed for heavy-duty electric vehicles, including trucks, buses, and ships. This system offers an impressive peak power delivery of up to 3.75MW through a single MCS connector, operating at voltages up to 1250V and currents up to 3000A.

The MCS setup generally requires cooled cables to manage the high-power transfer efficiently. For the highest power levels, such as Level 3 configurations, cooling systems may also be necessary on the vehicle side. The MCS can be categorized into different levels based on its power capabilities: Level 1 with uncooled cables can deliver up to 300A, Level 2 with cooled cables can handle up to 1000A, and Level 3, with advanced cooling, can support up to 3000A.

Designed to minimize charging time and reduce CO2 emissions for long-haul electric fleets, the MCS adopts a holistic approach based on the Combined Charging System (CCS). It also extends its support to light electric airplanes, ferries, and other marine vessels equipped with large-capacity batteries.

The high charging current requirements of up to 3000A necessitate either larger conductor cross-sections for the cables according to existing standards or additional measures in cable assembly. Despite these advancements, the system allows for manual charging by the customer or driver without the need for a supporting machine or robot. The MCS was officially introduced at the EVS35 in Oslo, Norway, in 2022.

Figure 2.5: MCS Plug (CHARIN)



The MCS is designed with several advanced requirements to support efficient and high-capacity charging for heavy-duty electric vehicles. Key requirements under discussion for the MCS include:

- **Single conductive plug**
- **Maximum voltage and current:** The system supports up to 1250V and 3000A of DC current, with potential peak power extensions reaching up to 4.5 MW
- **Communication standards:** It utilizes 10BaseT1S Ethernet for data transmission and ISO/IEC 15118-20 for vehicle-to-grid communication
- **Touch safety:** Compliance with UL2251 standards ensures that the system is touch-safe
- **Software-interpreted override switch:** An on-handle software-controlled override switch provides additional operational control and safety.
- **Automation capabilities:** The MCS is designed to support automated conductive charging as an advanced feature, enhancing operational efficiency and ease of use
- **UL (NRTL) certification**
- **Cyber-security**
- **Reverse power transfer (V2X):** The MCS supports bi-directional energy transfer, allowing vehicles to return power to the grid or other systems

2.5.1. Challenges

System side challenges: The adoption of the MCS faces several challenges. One major issue is the absence of an Indian standard for MCS, which complicates regulatory compliance and interoperability. Additionally, there is a need to assess the grid requirements and readiness for supporting MCS, as this system demands significant power capacity. The readiness of

EV charge management systems for integration with MCS also needs evaluation to ensure compatibility and functionality. Furthermore, the impact of MCS on battery life must be assessed to understand its long-term effects on battery performance and durability.

Vehicle side challenges: On the vehicle side, compliance with charging standards and ensuring modularity and flexibility in vehicle designs are crucial. Robust communication during high-power charging is essential to avoid disturbances caused by EMI. Active cooling systems are required to manage the significant heat generated, especially with currents exceeding 1000A, which necessitates handling over 30kW of heat dissipation. Electrical safety is a major concern, with the need for actively cooled disconnection mechanisms and managing high short circuit currents, which can exceed 80 kA for 1000A power levels and 100 kA for 3000A levels. The high-voltage (HV) architecture must meet ISO 5474-3 requirements, which may require alternative current-breaking methods to achieve rapid disconnection. EMI shielding is necessary to mitigate interference caused by higher currents. Additionally, the HV system introduces challenges such as increased weight, higher costs, larger cross-section cables requiring greater bending radii, and the need for robust connectors and effective thermal management of both the HV system and battery cells. Effective cooling of the entire cell surface is crucial due to substantial thermal losses.

Charging infrastructure and grid integration challenges: For charging infrastructure, establishing new MCS stations in logistic hubs, rest areas, and ports is necessary to support commercial vehicles. These stations must accommodate connection power in the megawatt range and ensure that power levels in the tens of megawatts are accessible even in remote locations. Grid-level load management, distribution, and balancing are critical, as a 3.75MW demand equates to the power consumption of approximately 3,000 households. Additionally, charge scheduling and early reservation systems need to be implemented for commercial vehicles, incorporating predictive route planning to optimize charging times and locations.

2.5.2. Recommendation

Conduct a thorough feasibility assessment to evaluate both grid and EV readiness for the MCS.

2.6. Note: Split charging systems (optimal power management)

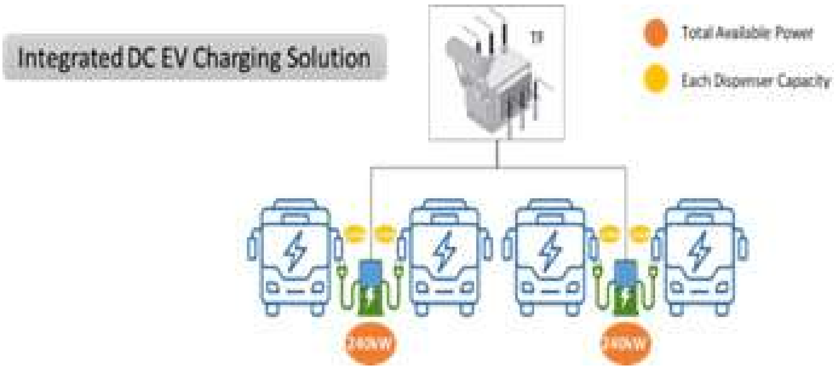
Current charging solutions, such as integrated DC Fast chargers, combine the charging gun and power cabinet into a single unit, providing modularity and quick deployment. However, these solutions are limited by their maximum capacity of two charging guns per unit. When charging demand decreases, the available charging capacity within the unit remains unused if the guns are engaged with EVs.

To address these limitations, the concept of Split Type DC Fast EV Chargers is gaining traction globally. This design separates the charging gun and power cabinet into distinct units, allowing for more intelligent power distribution. Split chargers facilitate simultaneous charging of multiple EVs by offering greater flexibility in power allocation. Unlike integrated chargers, split chargers can be configured with multiple dispenser posts, accommodating up to 12 single guns or 6 double guns, with individual power settings ranging from 40kW to 240kW or higher.

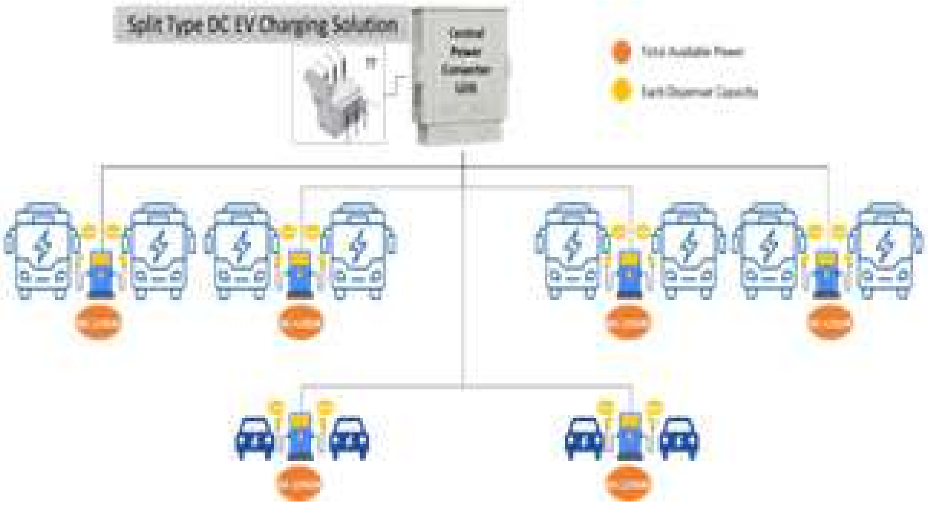
For example, a 630 kVA transformer paired with a 240kW dual gun integrated charger can only service 2 chargers, accommodating 4 EVs simultaneously. In contrast, a 480kW Split Type DC Fast Charger can manage up to 6 dispenser posts with dual guns each, enabling the simultaneous charging of 12 vehicles. Additionally, when fewer vehicles are present, the split charger's power output can be adjusted to 120kW or 240kW per individual dispenser.

Although integrated DC chargers currently offer lower initial costs, split DC chargers are expected to become more prevalent because of their ability to support multiple charging terminals concurrently. This flexibility meets the needs of a growing number of EV owners and increases revenue potential by maximizing the number of available charging points.

Conventional DC charger



Split type DC EV charging solution



General specifications:

Electrical	
Maximum output power	240kW/480kW
Input	AC415±10%V, 50/60Hz, 3P+N+PE
Output voltage	DC 200~1000V
Output current	200-250A for each dispenser
Full load power factor	>0.99
THD	≤5%
Full of Efficiency	>94% at full load
Interface and Control	
Charging connector number	12-16
Charging connector type	CCS2
HMI	15.6'' high brightness TFT touch screen display
RFID	ISO/IEC 14443A/B, ISO/IEC15393
Payment	APP/Payment, terminal(optional)
Network connection	Ethernet / 4G / Wi-Fi (optional)
Platform communication	OCPP 1.6J
Languages	English (Other Language on Request)
Environment	
Enclosure rating	IP55
Operating temp	-30 to 55degC
Storage temp	-40 to 70degC
Altitude	<2000m
Relative humidity	0 – 95% NC
General	
Cooling method	Forced FAN Cooling
Safety and Regulation	
Detection and protection	Insulation protection, Short circuit protection, Over/Under voltage protection, Over current protection, surge protection
Standard	IEC61851, IEC62196, ISO15118/DIN70121

03

INTEROPERABILITY IN EV CHARGING AND BATTERY SWAPPING

INTEROPERABILITY REFERS to the ability of various systems and processes to function together seamlessly, delivering the desired outcomes without friction. In the context of electric EV charging infrastructure, interoperability ensures that all components - EVs, charging stations, charging hardware, charging networks, and the grid - work together efficiently and in harmony.

An ideal EV charging experience should be as seamless as a modern mobile user's experience. For instance, a mobile user today can charge their device at public charging pods, such as those at airports, thanks to standardized plug designs. This hardware standardization allows users to connect their phones regardless of make or model. On the software side, applications are accessible and manageable uniformly, whether the device is Android- or IOS-based. Additionally, network access allows for automatic inter-regional and cross-network roaming without requiring user intervention to authenticate or adjust settings. This convenience results from a well-integrated technical and commercial infrastructure that operates behind the scenes.

However, in EV charging systems, achieving this level of interoperability presents challenges. The core issue lies in integrating the grid, the charger, the charging management system, and the EV itself. The complexity arises from the need to coordinate transactions across various 'black boxes,' each representing a different component of the charging ecosystem. Ensuring smooth communication and interaction among these disparate systems is crucial for a seamless EV charging experience.

3.1. Understanding interoperability in EV charging and battery swapping

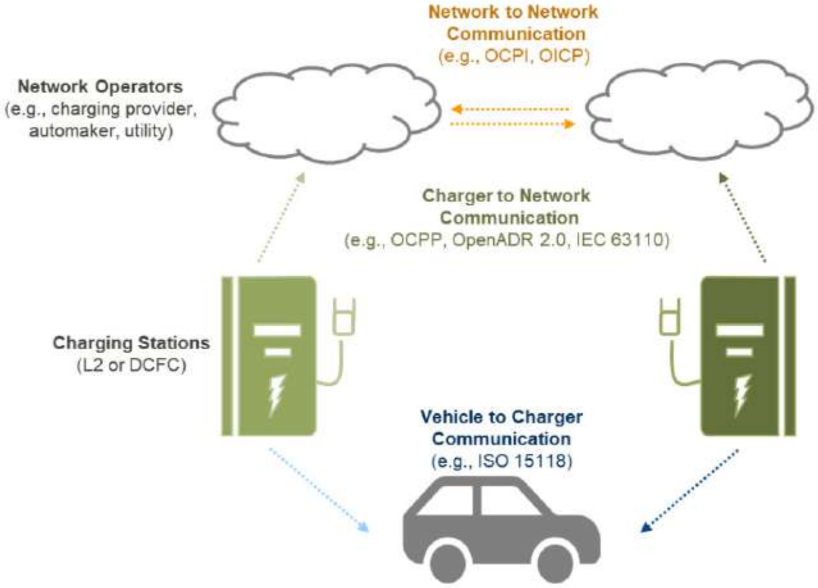
Interoperability in the EV charging ecosystem is influenced by three key domains: Vehicle to charger interoperability, charger to network interoperability, and network to network interoperability. Battery interoperability becomes essential for battery swapping, as indicated in figure 3.2.

- **Vehicle to charger interoperability** pertains to the compatibility and communication between the EV and the EVSE. This involves both electro-mechanical compatibility, such as pin-to-socket coupling, and communication compatibility between the EV's and the charger's charge point management system. Different hardware interfaces offer varying power levels and communication capabilities, affecting how well the EV and EVSE can interact.

- **Charger to network interoperability** involves the communication between the charging point and the CMS network. The CMS software helps manage the charging infrastructure by allowing CPOs to monitor usage, remotely control operations, authenticate users, and process payments. The Open Charge Point Protocol (OCPP) is a widely adopted standard that facilitates this communication, enabling OCPP-compliant EVSEs to interact with various networks. This standardization reduces risks for CPOs and manufacturers by ensuring broader compatibility across networks.

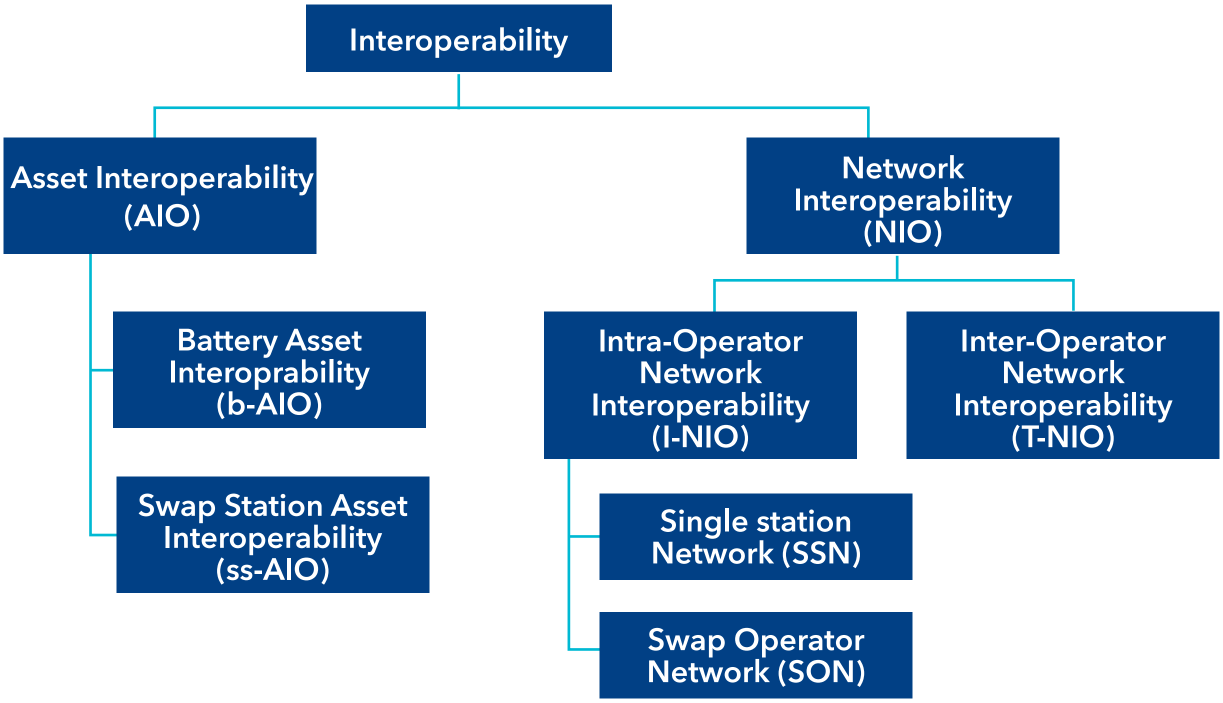
- **Network to network interoperability** addresses the ability of one charge point operator (CPO) or mobility service provider (MSP) to interact with another. Without interoperability, EV users might need to subscribe to each network separately, often through individual apps and fees. The standard solutions include peer-to-peer (P2P) agreements, where network operators directly collaborate to provide access across networks, and peer-to-hub (P2H) arrangements, where a central hub facilitates communication, roaming, billing, and settlement across multiple networks. The P2H model, prevalent in Europe, simplifies interactions among diverse providers by using e-roaming platforms. Protocols such as the OCPI and the Open Clearing House Protocol (OCHP) support these models, with OCPI being widely used for P2P and P2H transactions. Additionally, privately developed protocols like the e-Mobility Inter-operation Protocol (e-MIP) and the Open Intercharge Protocol (OICP) are popular in the EU, offering similar functionalities with some differences.

Figure 3.1. Interoperability diagram (Source MJ Bradley)



- **Battery interoperability** crucial for efficient battery swapping, encompasses three key aspects. First, hardware standardization ensures uniformity in battery design, including cavity pack size, terminal designs, and connections, facilitating compatibility across different vehicles and charging systems. Second, interoperability of Charging Management Systems (CMS) involves enabling communication between CMSs of various brands and battery chemistries, which is essential for seamless operation between different Battery Swapping Stations (BSSs) and electric vehicles (EVs). Lastly, interoperability between multiple BSSs ensures that different swapping stations can work together smoothly, allowing for efficient battery exchanges regardless of the station’s brand or location. This holistic approach to standardization and communication is vital for advancing battery swapping infrastructure.

Figure 3.2. Interoperability in battery swapping (Reference BIS Doc D: ETD 51 (20356) WC)



3.2. Standards for interoperability

3.2.1. Standards for vehicle to charger interoperability

India has established specific standards for vehicle-to-charger interoperability, focusing on defining acceptable pin-socket combinations and communication protocols between electric EVs and chargers. These standards are detailed in the Indian Standard IS-17017 Part-2, which covers plugs, socket outlets, vehicle connectors, and vehicle inlets. The standard addresses systems operating at AC 690V up to 250A and DC 1500V up to 200A, specifying the mechanical, electrical, and performance requirements necessary for compatibility. It also includes control mechanisms such as electronic locking of connectors to ensure secure and efficient operations.

Two key connector standards developed in India for LEVs are IS-17017 Part-2 Section-6 and IS-17017 Part-2 Section-7. IS-17017 Part-2 Section-6 pertains to DC connectors and vehicle inlets designed for LEVs, specifying systems with control means, a rated operating voltage up to 120V DC, and a rated current up to 100A. This section is in compliance with IS-17017-25, which outlines requirements for the control and communication between DC EV supply equipment and Light EVs, including characteristics, operating conditions, connection specifications, and electrical safety.

The newly introduced IS-17017 Part-2 Section-7, published in August 2023, establishes a connector standard supporting both AC and DC for LEVs. It specifies a rated operating voltage of 120V DC for 100A current and 240V AC for up to 32A. Additionally, this section proposes a new communication standard, IS-17017-Part31.

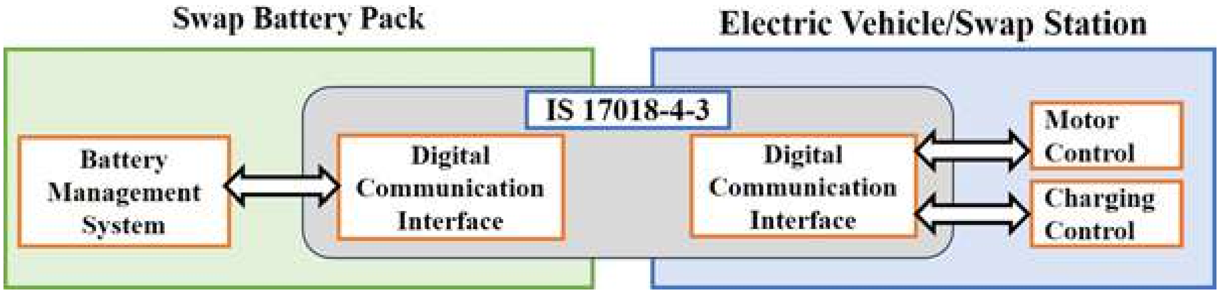
3.2.2. Standards for battery interoperability

The development of Indian standards for battery interoperability was guided by IEC PAS 62840-3:2021, which pertains to battery swap systems with a rated voltage up to 120V DC. The initial standard focused on LEV battery packs, specifically designed for scooters utilizing Lithium Iron Phosphate (LFP) battery chemistry. This approach ensures safe operation in LEVs that lack active battery cooling systems.

The development process considered several factors, including the need for scooter drivers to easily lift the battery pack, estimated to weigh around 10kg, and the minimum energy exchange requirement of 1kWh. Additionally, the preference for standard cylindrical cells commonly used in the two-wheeler industry was considered. Consequently, the recommended battery pack specifications include a voltage of 48V and dimensions of 18 cm x 16 cm x 31 cm. These packs are intended to power various electric vehicles such as e-scooters, e-rickshaws, e-autos, and e-quadricycles. Typically, a capacity of 1kWh is achievable with LFP battery chemistry, while Nickel Manganese Cobalt (NMC) chemistry can provide up to 1.5kWh.

For battery swap and discharging communication controls, the BIS P-Draft numbered ETD/51/17180 has been developed into the Indian Standards for battery swap communication protocols. This standard governs the data communication between the battery swap pack and the EV or the battery swapping station, ensuring effective control of both charging and discharging processes. The protocol aims to facilitate seamless interaction between components, thereby enhancing the efficiency and reliability of battery swapping operations.

Figure 3.3. Schematic for CAN communication



The Indian Standard for battery swap and discharging communication controls is based on the ISO standard for CAN communication, a protocol widely employed in the automotive industry for managing vehicle electronic systems. The specific protocol for Battery-as-a-Service (BaaS) battery pack control was initially developed at the IIT Madras Center for Excellence in Electric Vehicle Battery Technologies and later adapted by the BIS committee. This standard encompasses critical aspects such as identification and verification protocols at the battery, charger, and station levels. Developed entirely in India, this standard, in conjunction with the validated connector, offers a tailored solution for interoperable battery swapping that addresses the unique conditions and requirements of the Indian market. Additionally, IIT Hyderabad has finalized Draft Standard-3, which covers battery swap charging and discharging controls.

Note on Standard Development

IEC Technical Specification TS 63066 Low-voltage docking connectors for removable energy storage units was used as a reference to develop Indian Standard. The consultation process involved a public Call for Proposals, to select and finalise the design of the connector. The design ability was further constrained by the fact that only operationally proven connectors could be considered for developing the standards. The invitation sent to 100+ agencies (connector manufacturers, vehicle OEMs, vehicle aggregators, fleet operators, R&D labs, DISCOMs, testing agencies) seeking information on: Detailed Designs, Materials, Durability; Target Cost, how soon it can be manufactured in India, Technological advantages and Patent Status. Only 8 proposals were received, and only 4 provided sufficient details. Two were shortlisted. The ARAI analysed the data and test reports regarding the communication or signal interface; flammability tests, high voltage test; operating temperature; and mating cycles ≥ 10,000 and manufacturability. Demonstration of the working of the system was also requested. One of the connectors was chosen for inclusion in the draft Indian Standards.

Note: The Indian Standards for Battery as a Service for LEV was developed and approved by the BIS technical committee. However, it has not been adopted.

3.3. Challenges and solutions for interoperability

3.3.1. Use of non-standardized connectors in LEVs

There is a significant lack of uniformity among OEMs in the 2W and 3W sectors regarding connector selection for LEVs. Many OEMs, particularly those focusing on assembled models, utilize non-standard connectors. These connectors often feature diverse hardware designs, rudimentary or non-existent communication protocols, and limited charging capacities, with many only supporting currents up to 75A. In contrast, standardized connectors like Type 6 and Type 7 are designed to accommodate a wide range of vehicles—including e-bikes, scooters, motorcycles, delivery scooters, e-rickshaws, e-ATVs, e-autos, electric forklifts, and golf carts—and have garnered broad acceptance across the country. The Type 6 and Type 7 connectors are already localized and manufactured in India, demonstrating their suitability and widespread applicability.

3.3.1.1. Recommendation

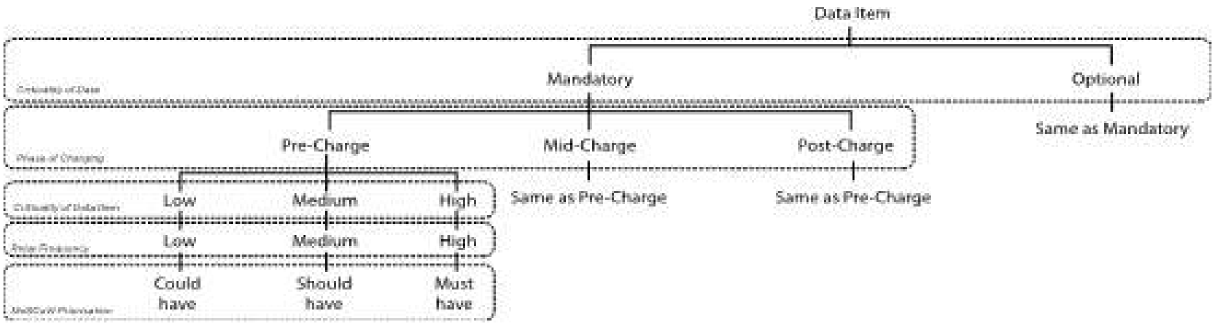
Support the development and adoption of low-cost standardized connectors to facilitate greater consistency and interoperability in LEV charging infrastructure.

3.3.2. Charger to CMS communication for LEVs

The existing communication standards for EV charging sessions were predominantly designed for the four-wheeler market. However, the cost dynamics for implementing standardized communication protocols for LEVs differ significantly from those for four-wheelers. For instance, charging a 35-kWh EV battery may cost up to ₹700, assuming an electricity rate of ₹20 per unit, whereas charging an LEV might cost only ₹60. Presently, the software cost per charging session for LEVs, including data storage and transfer necessary for interoperability, is approximately ₹3. This represents 10% of the total charging cost for an LEV, compared to just 0.42% for a four-wheeler.

This cost discrepancy stems from the design of communication protocols, which includes factors such as data packet size and the frequency of data relays to support various features. To better align the cost structure with the needs of the LEV charging ecosystem, one effective optimization strategy involves segmenting data packets and adjusting relay frequencies according to the charging session stages: Pre-Charge, Mid-Charge, and Post-Charge (see fig.3.4). Each stage may not require uniform relay frequencies, and data packets can be divided into essential information (e.g., discoverability, charger status, payments) and optional features (e.g., slot booking, postpaid billing, real-time vehicle State of Charge). This approach of tailoring data segmentation and relay frequency can significantly reduce storage and data transfer costs, especially in large-scale infrastructure deployments.

Figure 3.4. Schematic on segmentation of data packets



3.3.2.1. Recommendation

To achieve optimal interoperability within the charging infrastructure for LEVs, addressing the current shortcomings in communication protocols designed primarily for four-wheelers is essential. These flaws impact both the implementation and operational cost structures, ultimately affecting user experience. The following steps are recommended:

Collaborate with protocol-defining organizations: Work with established bodies to refine and streamline the communication stack specifically for LEVs, ensuring that the protocols are well-suited to the unique requirements of two- and three-wheelers.

Develop LITE versions of existing protocols: Create simplified versions of existing communication stacks tailored to the cost structures prevalent in the Indian LEV market.

This approach could be replicated in other developing regions where LEVs are a primary transportation mode.

Enhance user experience: Focus on improving the user experience by reducing barriers to EV adoption and standardizing interaction patterns, potentially through the introduction of a Plug & Charge model.

Implement certification programs: Establish certification programs to ensure that all deployed products meet the established standards, promoting consistency and reliability in the charging infrastructure.

3.3.3. Network-to-network interoperability

In India, the landscape of EV charging infrastructure is characterized by a multitude of CPOs and Mobility Service Providers (MSPs), each managing their own networks of charging stations. Each operator often employs proprietary customer-facing applications, which EV users must download and subscribe to in order to access their services.

Achieving effective network-to-network interoperability among these operators necessitates the sharing of critical data, including the location, specifications, and operational status of charging stations, as well as tariff information and user authentication details. However, many network operators view subscriber base and charger utilization data as proprietary and sensitive. This apprehension creates significant challenges for cooperation, as operators are often reluctant to share such data, even with neutral third parties. Addressing these concerns and fostering a collaborative approach is essential for enhancing interoperability and streamlining the EV charging experience.

An indigenous solution to address the challenge of network-to-network interoperability is the concept of the UEI. Developed by a specialized team of experts, UEI operates as a decentralized network that enables location-aware EV chargers to be discovered and accessed by any network-enabled application. It employs the BECKN protocol, a versatile interoperability framework applicable across various digital markets.

Like the UPI, which facilitates seamless financial transactions between different banks and customer accounts, UEI aims to streamline EV charging across diverse CPOs and EV users. By democratizing access to both large and small CPOs and eliminating the need for multiple applications, UEI represents a significant paradigm shift in enhancing EV charging accessibility. This approach allows for dynamic data sharing and simplifies the charging experience, thus improving overall user convenience and operational efficiency.

The UEI leverages the BECKN protocol to facilitate a range of charging-related transactions, including charger discovery, booking, activation, and payment, between users and charge points. It offers several key advantages over existing network protocols like OCPI:

Universal access: Unlike traditional systems where users must rely on specific charging network apps, UEI allows users to access chargers through any app registered as a buyer app within the network. This universal accessibility enhances user convenience and flexibility.

Selective data sharing: UEI addresses a major concern of CPOs by requiring them to share data only in response to specific requests. This contrasts with platforms or roaming hubs that necessitate continuous sharing of dynamic data such as charger availability, location, and tariffs.

Cost-effective discoverability: Smaller CPOs, who might struggle with discoverability without partnering with e-Mobility Service Providers (e-MSPs) or other CPOs, can onboard with UEI at significantly lower costs. This provides them access to a broader marketplace without substantial financial investment.

Non-disruptive integration: UEI offers an alternative marketplace that complements existing business models. CPOs can continue with their subscriber-based models, engage in peer-to-peer contracts, or participate in aggregator platforms without exclusivity or conditionality. UEI does not disrupt current business practices but provides an additional market network.

Direct financial transactions: UEI allows charging operators to receive payments directly into their accounts, eliminating the need for intermediaries and potentially reducing transaction costs.

Simple Operational Flow of UEI

***User query**: The user initiates a query for charging through any UEI-registered application (such as Google Maps, GPay, Paytm, or BookMyShow).*

***Network relay**: The request is transmitted to the UEI network and forwarded to all seller apps (typically charge point operators or CPOs) registered with UEI.*

***Response from CPOs**: CPOs respond automatically with relevant details including charge location, type, capacity, and tariffs. The user receives multiple responses from CPOs within the same application interface.*

***Selection and connection**: The user selects a preferred charging point from the available options. The UEI network facilitates direct communication between the user and the chosen CPO, enabling the sending and receiving of start and stop commands for the charging session.*

***Payment**: Upon completion of the charging session, the CPO provides the UPI ID associated with their charger. The user pays directly to this UPI ID, avoiding additional transaction costs. If UPI is not available, the participating CPOs can work directly with the UEI app provider for reconciliation.*

Note: A pilot with the Central Govt. on top of UEI is under progress to demonstrate an interoperable charger interoperability framework. Once the pilot program is complete, the API specification and registration flows that CPOs and User apps can follow to onboard onto Unified Energy Interface will be published.

3.3.4. Battery swapping standards and interoperability

Battery swapping involves managing four critical identities to ensure a smooth and interoperable system: Vehicle Identification Number (VIN), Battery Identification Number (BIN), Battery Charging Station Number (BCSN), and BaaS Outlet Number (BON).

In scenarios where both the vehicle and battery are from the same operator, the Central Management System (CMS) of that operator facilitates seamless management. This system ensures that even if a battery pack is swapped at a distant station, the transition remains smooth and controlled by the operator's CMS, which oversees authentication and verification processes.

However, in cases where the vehicle, battery packs, and swap stations are from different operators, interoperability becomes crucial. This requires a communication framework between the CMS of various BaaS operators.

To achieve full interoperability, a standardized system will be implemented using OpenAPI. This will outline the interfaces and methods for exchanging specific codes among BaaS operators, thereby providing a unified and seamless experience for EV consumers across different networks and operators.

3.3.4.1. Recommendation

To ensure that the battery swapping system specified by the standards is reliable, safe, and robust, a comprehensive testing and validation program is essential. This program will not only validate the system but also inform policy and regulatory frameworks.

Leading companies should be invited to prototype and deliver their systems to designated testing laboratories for evaluation across several key aspects:

> » **Overall system demonstration:** Testing should include a complete system demonstration using Battery Packs and Battery Swapping Stations (BSS) to ensure all components function as intended.
>
> » **Swap connector and communication system**: The swap connector and communication systems need rigorous testing to verify their performance and compatibility with the standards.
>
> » **Backend interoperability:** Evaluation of backend systems to ensure interoperability between different operators' Central Management Systems.

These measures will familiarize companies with the interoperability requirements specified by the standards and provide a head start in developing prototypes and conducting validation trials. With these steps, battery swapping for CPOs will become a significant and efficient feature in Indian cities.

04

RECOMMENDATIONS AND WAY FORWARD

THE KEY ACTION POINTS emerging from R&D Roadmap for undertaking new R&D projects / program development specifically in the TRL 4 – TRL 6 bands are summarised below.

4.1. Development of universal infrastructural socket (UIS) for LEV Charging

The universal infrastructure socket (UIS) is envisioned to facilitate charging for LEVs using international communication protocols and to serve as a cost-effective, distributed charging solution across India. The UIS will support a variable DC power range of 48V to 500V, with charging capacities ranging from 2 kW to 22 kW and aims to simplify the charging process with a detachable cable system.

The UIS system will include a type-2 plug on the charger side, with the vehicle side of the cable accommodating any connector that complies with Indian standards. The development will focus on:

- » **Repurposing the type 2 connector:** Adapt the Type 2 connector for both power transfer and communication.
- » **Developing a communication-capable cable:** Integrate in-cable intelligence to handle various charging protocols, including an embedded microprocessor to translate data communication into a common format, and a BLE module for communication with the charger.

4.1.1. Way forward

- **Product development support**: Initiate development of the UIS and charging cable with integrated electronics. Form an industry-academia consortium to drive innovation and collaboration.
- **Product testing and field trials:** Conduct comprehensive testing and field trials.
- **Pilot implementation:** Deploy the UIS and cables at various public charging stations.
- **Extension to Renewable Energy and Microgrid Charging Parks:** Expand the UIS implementation to include renewable energy (RE) and battery-powered microgrid charging parks, integrating smart power management and vehicle-to-grid (V2G) capabilities.

4.2. Development of low-cost LEV-DC chargers

DC charging systems offer advanced capabilities such as negotiating charging power, monitoring battery status, and performing real-time safety checks. These features ensure efficient and safe charging, which can significantly reduce charging times and enhance charger utilization for LEVs. Despite these advantages, current LEV-DC chargers in India have limited local content in core components such as rectifiers and electronic parts, which constrains widespread deployment.

Developing affordable DC chargers for LEVs involves enhancing local production of essential components and integrating advanced features to support fast, safe, and efficient charging. The objective is to improve the accessibility and performance of public charging stations through increased indigenization.

4.2.1. Way forward

1. **Technology development support**: Development of a low-cost LEV-DC chargers with a target capacity of 12 kW by formation of an industry-academia consortium.
2. **Pilot deployment and field trials:** Conduct extensive testing and refinement of the indigenously developed chargers to ensure reliability, safety, and performance. Deploy the chargers in selected public charging stations for real-world trials and gather feedback to inform further improvements.

4.3. System design and pilot implementation of DC microgrid-based Park-bay charging

The integration of LEV charging infrastructure into existing LT grids is feasible without significant grid augmentation due to the manageable power requirements of LEVs. However, the proliferation of multiple public chargers could exacerbate issues in areas with weak distribution networks. To address this, a solar photovoltaic (PV) and battery-powered microgrid system presents a promising solution for largescale deployment while alleviating grid congestion. This system leverages renewable energy sources and energy storage to enhance grid stability and support extensive charging infrastructure. The optimization of energy efficiency within such a system requires testing various control strategies and algorithms, as their effectiveness can vary depending on specific use cases. Implementing multiple pilot projects will enable the evaluation and refinement of these strategies, ensuring their suitability for broader application. These pilots will help streamline control mechanisms and provide insights into the best practices for managing energy within DC micro-grid-based charging stations.

4.3.1. Way forward

- To advance the development of DC microgrid-based park-bay charging systems, a pilot project should be initiated to demonstrate the viability of solar PV and battery-powered microgrids for EV charging.
- An ideal starting venue for this pilot would be a government office parking area, such as the DST Campus, to validate the system's performance and integration in a controlled environment.

4.4. Testing and validation program for building interoperability in battery swapping

Battery swapping for electric vehicles involves managing four critical identifiers: the vehicle identification number (VIN), battery identification number (BIN), battery charging station number (BCSN), and BaaS outlet number (BON). When the vehicle and battery are operated by the same entity, the Central Management System (CMS) of the operator ensures seamless integration and management, even across distant swap stations. The CMS monitors various battery packs and swap stations, overseeing authentication and verification processes.

For interoperability between different operators, the system must facilitate communication across disparate central management systems. This requires establishing a standardized protocol through an application programming interface (OpenAPI) that outlines the methods for exchanging specific codes and information among BaaS operators. The development of these standards is crucial for ensuring a unified and efficient experience for users.

To advance this, a structured testing and validation program is necessary. This program should involve developing and validating prototypes, conducting trials in testing laboratories, and evaluating the system's performance. Implementing these measures will help integrate battery swapping technology effectively, making it a significant feature in Indian cities and enhancing the overall EV infrastructure.

4.4.1. Way forward

» To ensure the successful integration of battery swapping systems and to support the development of robust policies and regulations, a comprehensive testing and validation program should be established.

» Leading companies will be engaged to prototype and deliver their systems to designated laboratories for thorough testing.

» The evaluation will focus on several key aspects:

- **Overall system level demonstration:** Testing will involve the complete setup, including Battery Packs and Battery Swapping Stations (BSS)
- **Swap connector and communication system**
- **Backend interoperability**

4.5. Standard development and validation for Dual Gun charging

Dual-gun charging technology, already in use by several Indian OEMs such as Switch Mobility, employs the CCS2 protocol to deliver power up to 180 kW. However, to prevent interoperability issues and ensure seamless deployment across India, it is crucial to develop and standardize dual gun charging protocols. The absence of standardized practices could result in non-functional charging stations, potential errors, and misuse or misinterpretation by OEMs, charger manufacturers, and component suppliers. Additionally, user guides and safety features associated with dual-gun charging must be thoroughly validated before the technology is widely adopted. Establishing clear standards and validation processes will facilitate smooth integration, enhance user safety, and support the technology's broad deployment in the Indian market.

4.5.1. Way forward

To ensure the successful and widespread adoption of dual gun charging technology in India, the following steps are recommended:

> BIS has finalised the standard for dual gun charging and it is under advanced stage for printing
>
> **Validation:** Engage authorized organizations to validate the developed standards.

4.6 Technology assessment, validation and field trials for Pantograph-based charging

The implementation of Electric Bus Automated Pantograph Charging Station IS-17017-3-1 and the Pantograph Connection System defined by IS-17017-3-2 is yet to commence, highlighting a critical need for action to establish interoperable heavy charging infrastructure in India. This requires collaboration with OEMs and EVSE manufacturers to design and support pantograph-charging methods. Additionally, assessing the impact of pantograph charging as an opportunity charging system on the grid is essential. Prioritizing these actions will ensure the development of a robust, interoperable charging infrastructure for heavy-duty EVs in the country.

4.6.1. Way forward

- Supporting a case study and evidence building to compare cable-based vs. pantograph-based charging systems, including a cost analysis over a 7-10 year period and evaluating operational efficiency. This includes understanding the potential reduction in battery size when adopting this system, assessing the reliability and availability of batteries, evaluating battery performance, and comparing it with other charging technologies. Additionally, it will assess availability and access to power across India and RE-integration.

- Support technology development for pantograph charging (pantograph-down and overhead continuous pantograph design) through industry-academia collaboration.
- Supporting pilot projects and trial-runs for pantograph-down and/or continuous pantograph systems.

4.7. Technology assessment, standard development, lab validation and field trials for catenary charging systems, inductive charging systems and megawatt charging systems

Catenary, inductive and mega watt charging systems do not have a use-case in India. Before supporting an India specific use case through field trials, it would be important to develop the standards for these systems. Technology assessment and lab validation will be required to ensure that safety and power transfer protocols are defined and implemented.

4.7.1. Way forward

> » Support the development of Indian standards for these charging technologies
>
> » Support case studies and evidence building, including cost analysis for pilot and scaled projects, and assess the availability of and access to power across India and the integration of renewable energy sources
>
> » Support technology development through lab validation of necessary connectors and charging components
>
> » Support pilot and trial runs for these technologies

GLOSSARY

EV = Electric Vehicle

KW = Kilo Watt

OEM = Original Equipment Manufacturer

UEI = Unified Energy Interface

DC = Direct Current

HT = High Tension

LT = Low Tension

SiC = Silicon Carbide

GaN = Gallium Nitride

CCS = Combined Charging System

UPI = Unified Payment Interface

LEV = Light Electric Vehicle

LECCS = Light Electric Combined Charging System

NMC = Nickel Manganese Cobalt

LFP = Lithium Iron Phosphate

EVSE = Electric Vehicle Supply Equipment

CP = Control Pilot

PP = Proximity Pilot

CMS = Central Management System

BIN = Battery Identification Number

BCSN = Battery Charging Station Number

VIN = Vehicle Identification Number

BON = BaaS Outlet Number

DISOM = Distribution Company

ISO = International Organisation for Standardisation

ARAI =Automotive Research Association of India

GCC = Gross Contract Structure

CESL = Convergence Energy Services Limited (CESL)

EESL = Energy Efficiency Services Limited (EESL)

FAME = Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME)

SECC = Supply Equipment Communication Controller (SECC)

EVCC = Electric Vehicle Communication Controller (EVCC)

BIS = The Bureau of India Standards (BIS)

ACD = Automated Connection Device

CAN = Controller area network

VCU = Vehicle Control Unit

CPO = Charge Point Operator

FIDE = Foundation for Interoperability in Digital Economy

ONDC = Open Network for Digital Commerce

OICP = Open Intercharge Protocol

OCPI = Open Charge Point Interface

MSP = Mobility Service Provider

CAPEX = Capital Expenditure

OPEX = Operating Expenses

TOD = Time of day

EODB = Ease of doing business

BRAP = Business Reforms Action Plan

SOP = Standard Operating Procedure

BLE = Bluetooth Low Energy

TRL = Technology readiness levels

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