Republic of Tunisia
Ministry of Industry, Energy and Mines (MIME)
Société Tunisenne de I'Electricite et du Gaz (STEG)

The Project for Low Carbon and Stable Supply at Power System in Tunisia

Volume 2

Project Completion Report

July 2026

Japan International Cooperation Agency (JICA)
Tokyo Electric Power Services Co., Ltd.

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Presentation Material 2- 1

Activity 2-1-1 & 2-1-2 Review Technology Options for the Penetration of EV

Review Technology Options for the Penetration of EV

Activity 2-1-1, 2-1-2

JICA Expert Team

September 2024

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this presentation

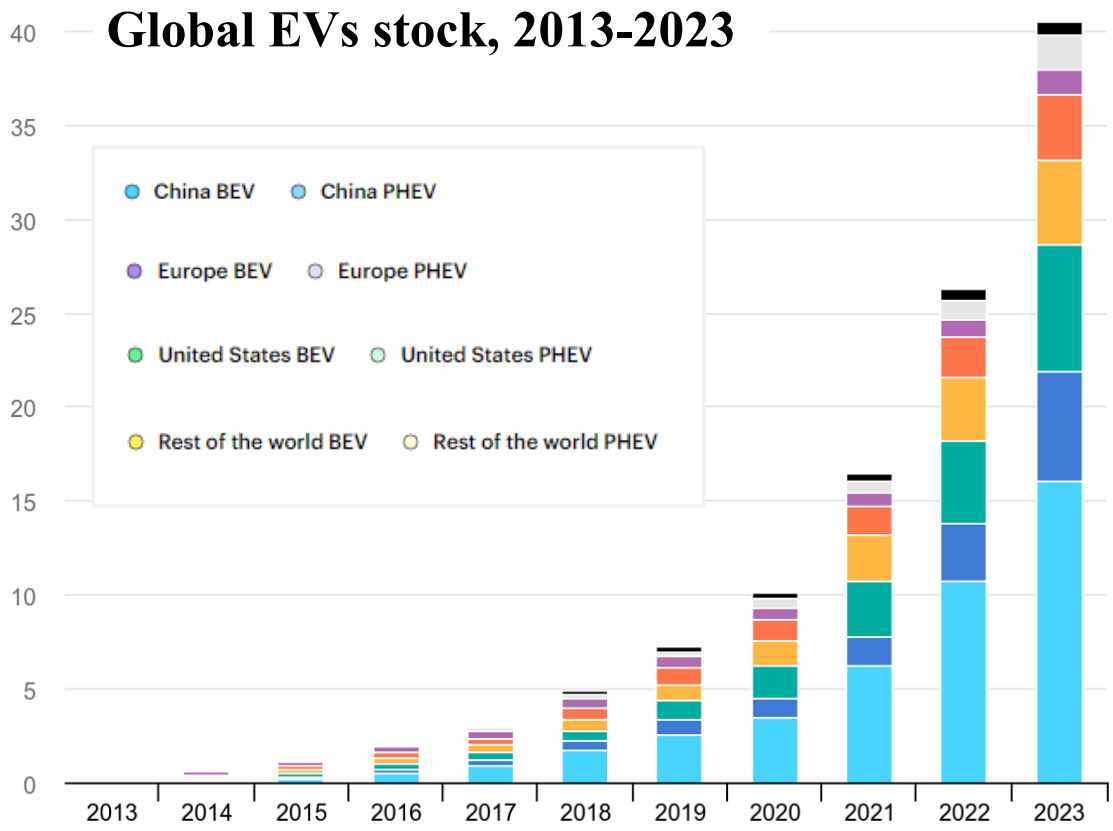
Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-1-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

Contents

1. Introduction
2. Comparison of Batteries
3. IRVE
4. Charging Method
5. Smart Charging Technology
6. Case Studies in Japan

1. Introduction

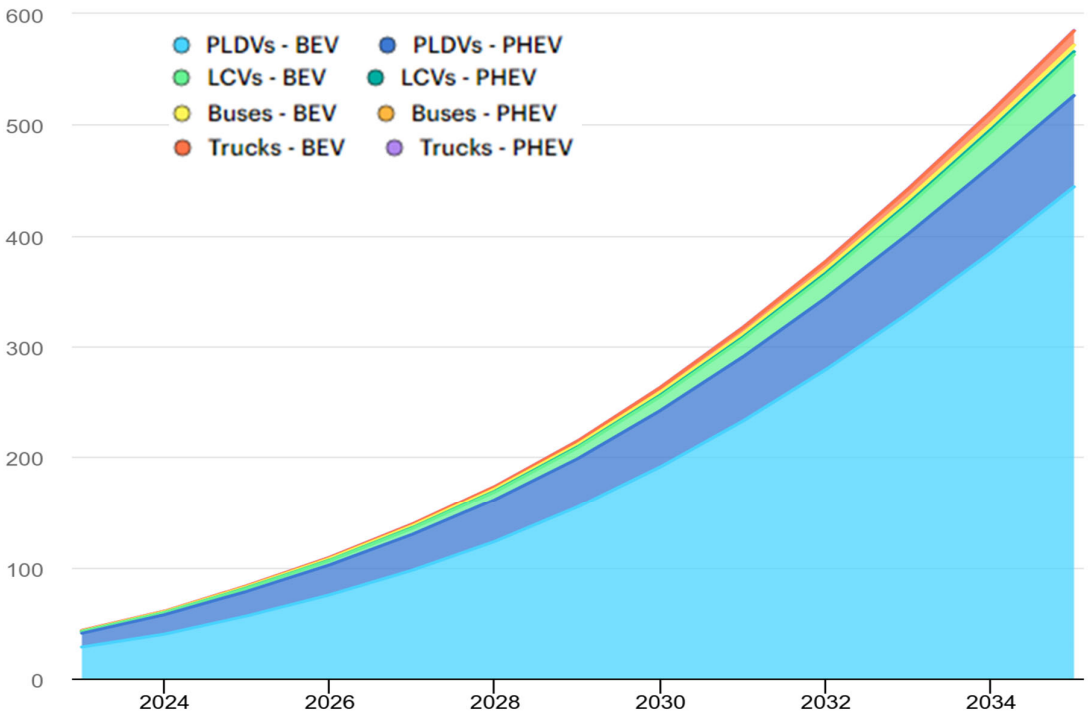
1. Introduction



Source: Trends in electric cars (International Energy Agency: IEA)
https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars

1. Introduction

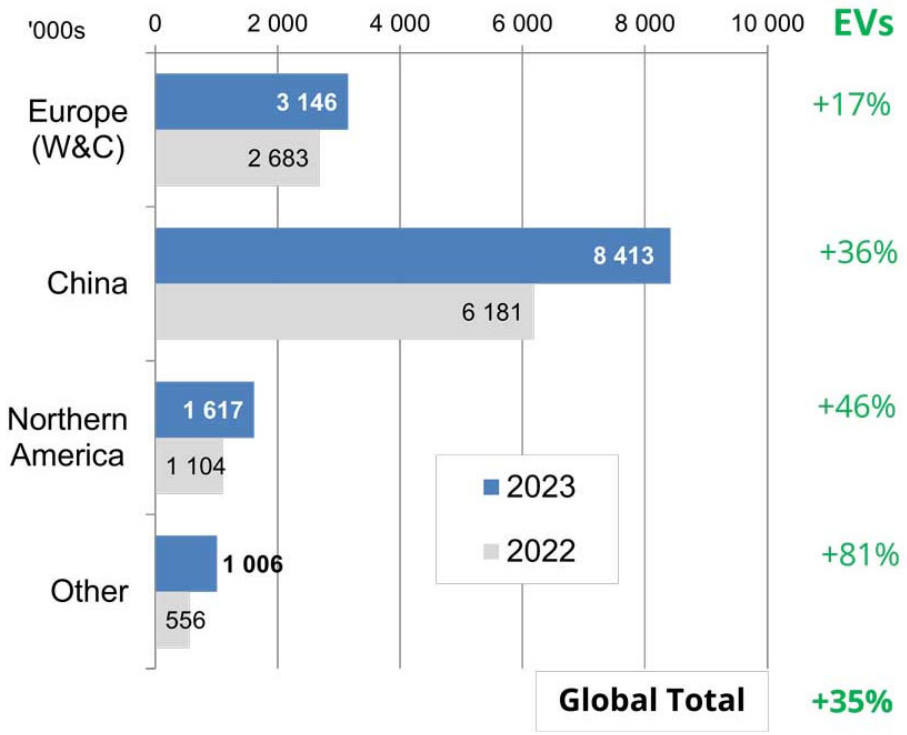
EVs stock by mode in the penetration scenario, 2023-2035



Source: Outlook for electric mobility (International Energy Agency: IEA)
https://origin.iea.org/reports/global-ev-outlook-2024/outlook-for-electric-mobility

1. Introduction

BEV+PHEV Sales and % growth for 2023 vs 2022



Source: Global EV Sales for 2023（EV VOLUMES）
https://ev-volumes.com/news/ev/global-ev-sales-for-2023/

1. Introduction

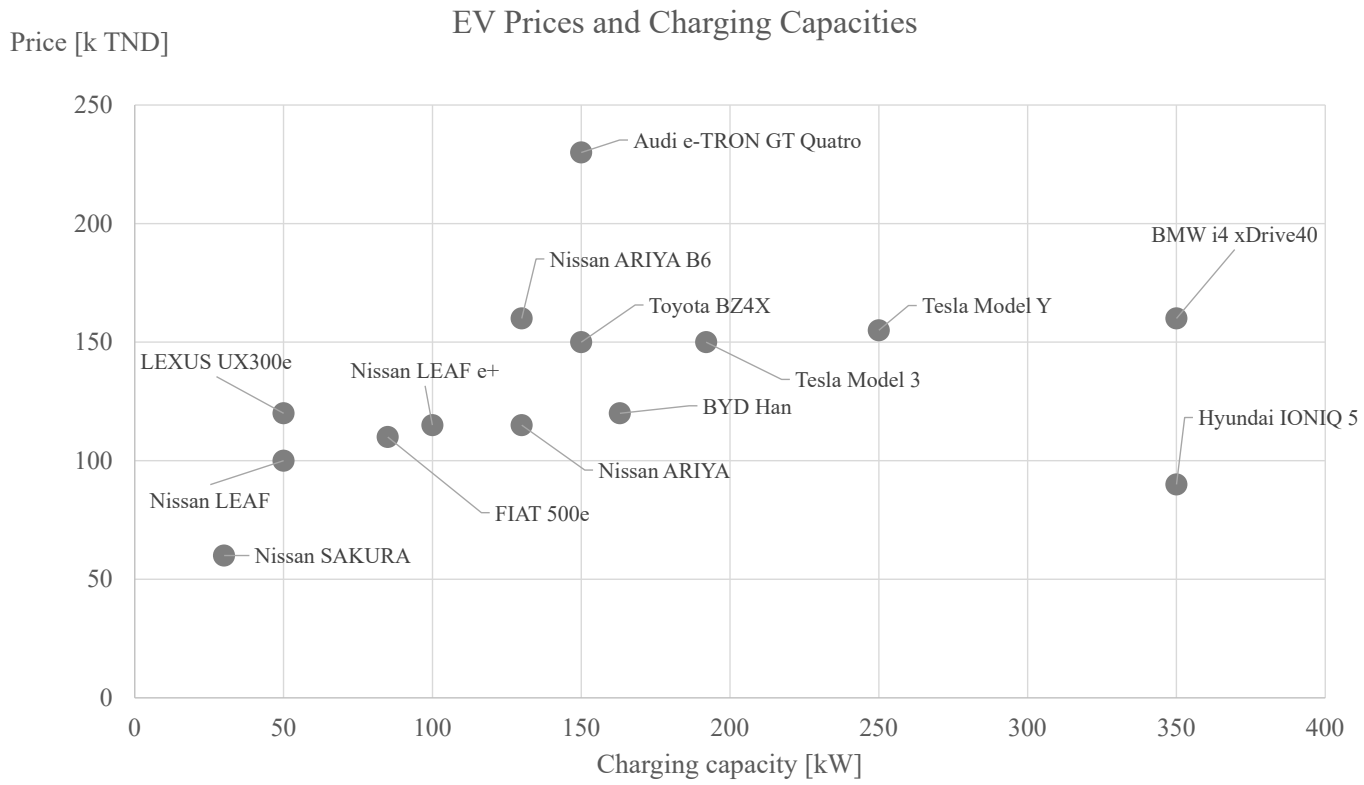
■ Advantages of EVs

- ➢ CO2 reduction
- ➢ High energy efficiency
  (The distance that can be driven with the energy equivalent to 1 liter of gasoline is 12.8 km/L for gasoline cars, and 42 km/L for EVs)
- ➢ Reduced maintenance costs
  (Number of parts: 100,000 for gasoline cars, 10,000 for EVs)

■ Challenges of EVs

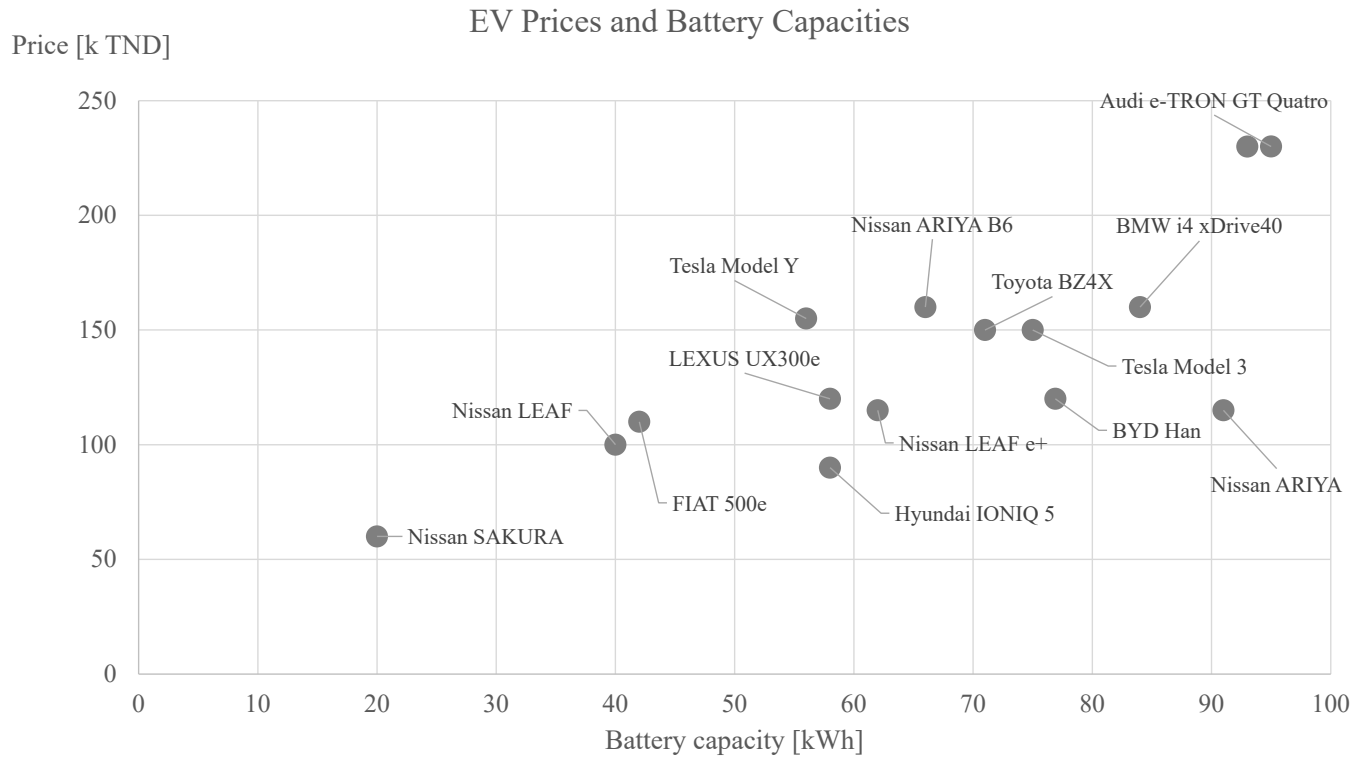
- ➢ Range: Limited distance that can be traveled on a single charge
- ➢ Charging time: Approximately 30 minutes required for rapid charging (depends on battery capacity & IRVE charging speed)
- ➢ Initial cost: 170-230% more expensive compared to gasoline cars of the same class (Gasoline cars: 39,000 to 75,000 TND, EVs: 65,000 to 172,000 TND)

1. Introduction



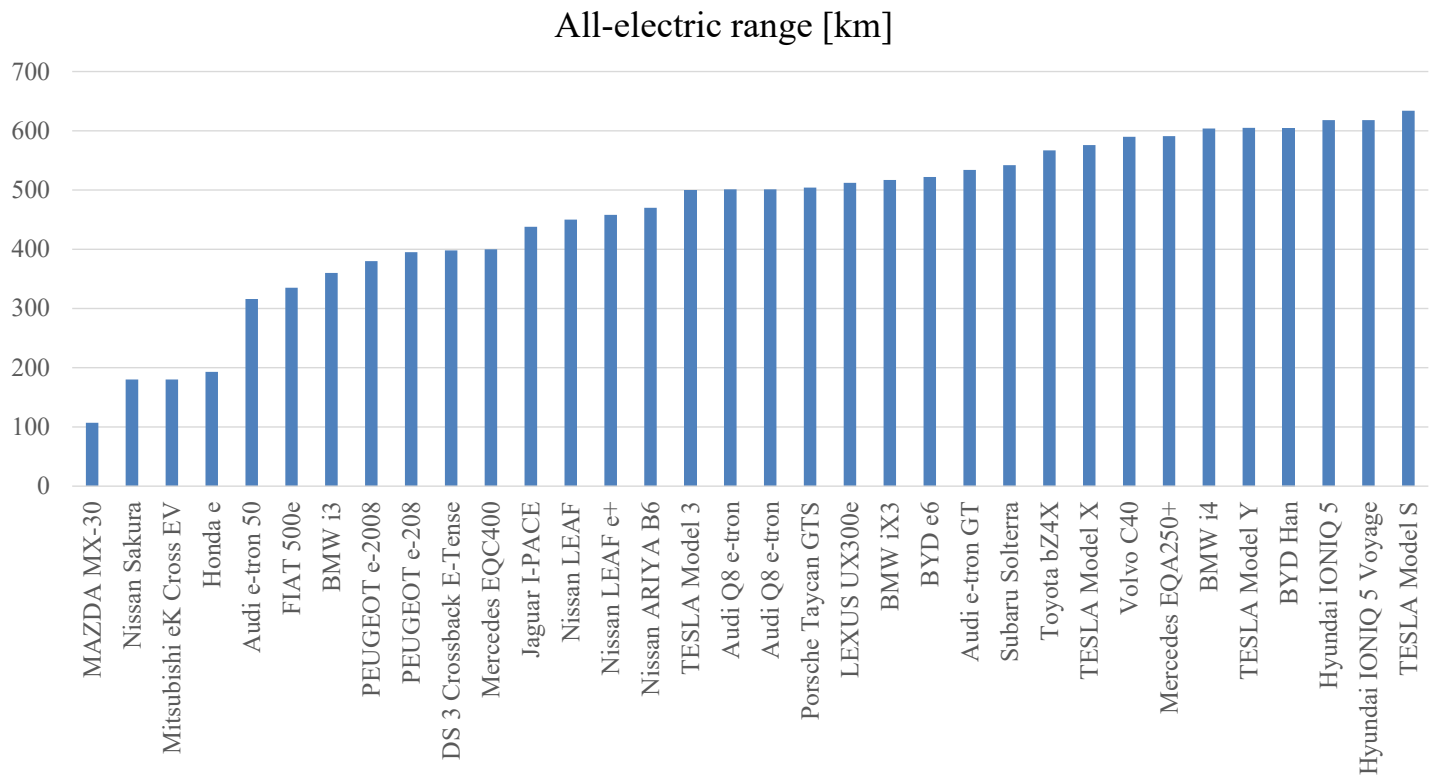
Source: Created by the expert team based on various sources

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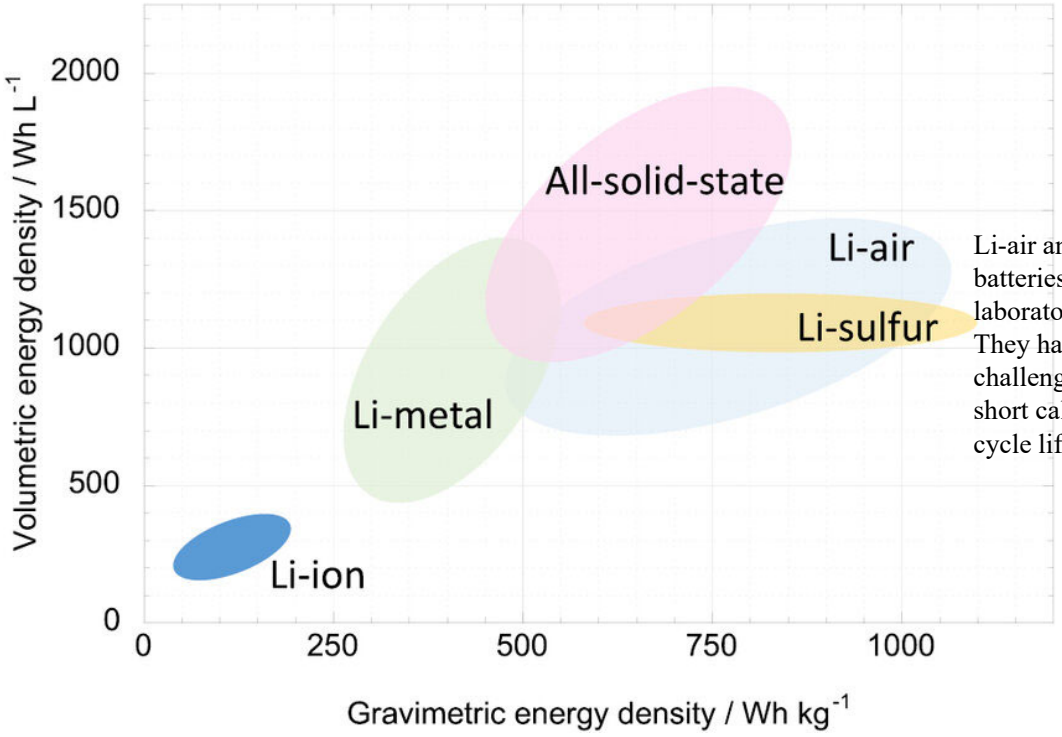
1. Introduction



Source: Created by the expert team based on various sources

2. Comparison of Batteries

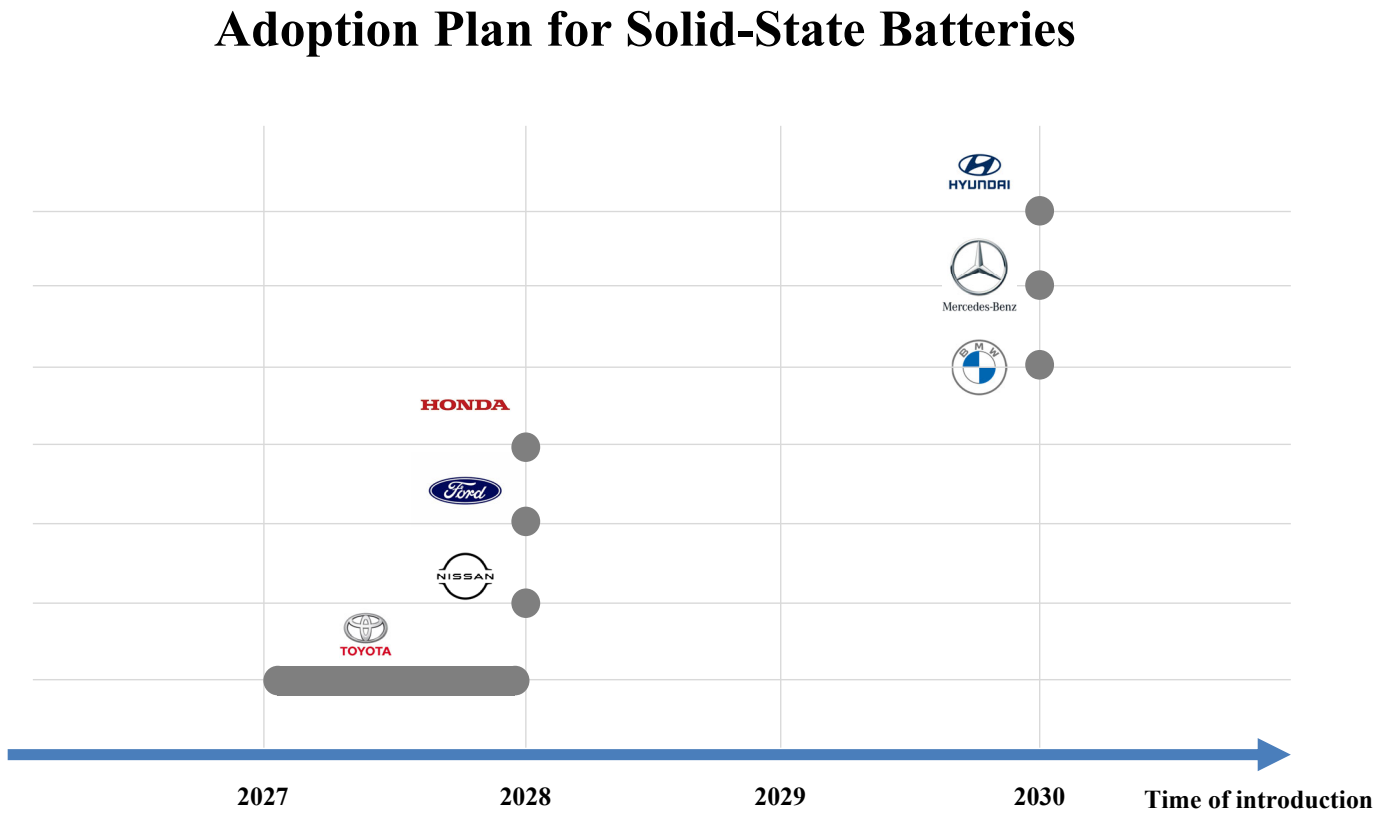
2. Comparison of Batteries



Li-air and Li-sulfur batteries are at the laboratory stage. They have particular challenges such as short calendar and cycle life.

Source: Recent progress for all solid state battery using sulfide and oxide solid electrolytes - Journal of Physics D: Applied Physics, Volume 52, Issue 10, article id. 103001 (2019)
https://www.researchgate.net/publication/329578389_Recent_progress_for_all_solid_state_battery_using_sulfide_and_oxide_solid_electrolytes

2. Comparison of Batteries



Source: Created by the expert team based on various sources

2. Comparison of Batteries

Comparison of Lithium-ion battery and Solid-state battery

Features	Lithium-ion battery	Solid-state battery
Structure	Liquid electrolyte	Solid electrolyte
Safety	Risk of ignition from overheating or short-circuiting. Possibility of liquid leakage.	High stability even at high temperatures. Lower risk of ignition.
Charging Speed	Rapid charing is possible.	Theoretically faster charing speeds expected, but technical challenges remain.
Cycle Life	500 - 1,500 cycles	More than 5,000 cycles expected.
Cost	Widespread and therefore cheaper.	Currently expensive, but reductions are expected in the

Created by the expert team based on various sources

3. IRVE

3. IRVE

- Definition of IRVE
  - ➢ Infrastructures de Recharge pour Véhicules Électriques (French)
  - ➢ Refers to all charging facilities for electric vehicles.
  - ➢ Includes all charging points, both public and private.
- The development of rapid charging infrastructure is essential for the widespread adoption of EVs. It is particularly important to consider the traffic census and implement the optimal placement of IRVE.



Public roads (rapid charging)



Dealerships (rapid charging)



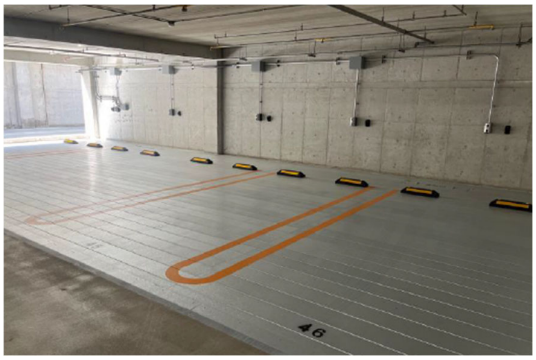
Service areas (rapid charging)

Source: 7th Review Meeting on the Promotion of Charging Infrastructure Development: Secretariat Materials (Ministry of Economy, Trade and Industry)
第7回 充電インフラ整備促進に関する検討会 事務局資料（経済産業省）
https://www.meti.go.jp/shingikai/mono_info_service/charging_infrastructure/pdf/007_03_00.pdf

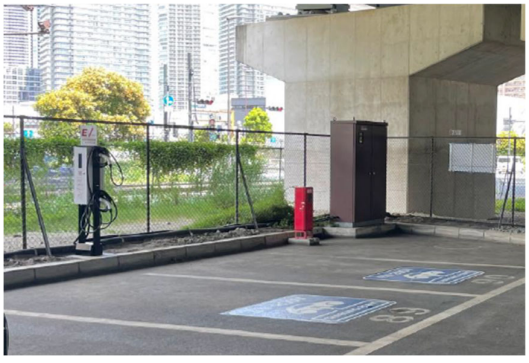
3. IRVE



Commercial facilities (standard charging)



Residential complex parking lots (standard charging)



Monthly parking lots (standard charging)



Hotels (standard charging)

Source: 7th Review Meeting on the Promotion of Charging Infrastructure Development: Secretariat Materials (METI)
第7回 充電インフラ整備促進に関する検討会 事務局資料（経済産業省）
https://www.meti.go.jp/shingikai/mono_info_service/charging_infrastructure/pdf/007_03_00.pdf

3 The Evolution of Charging Infrastructure and Global Trends

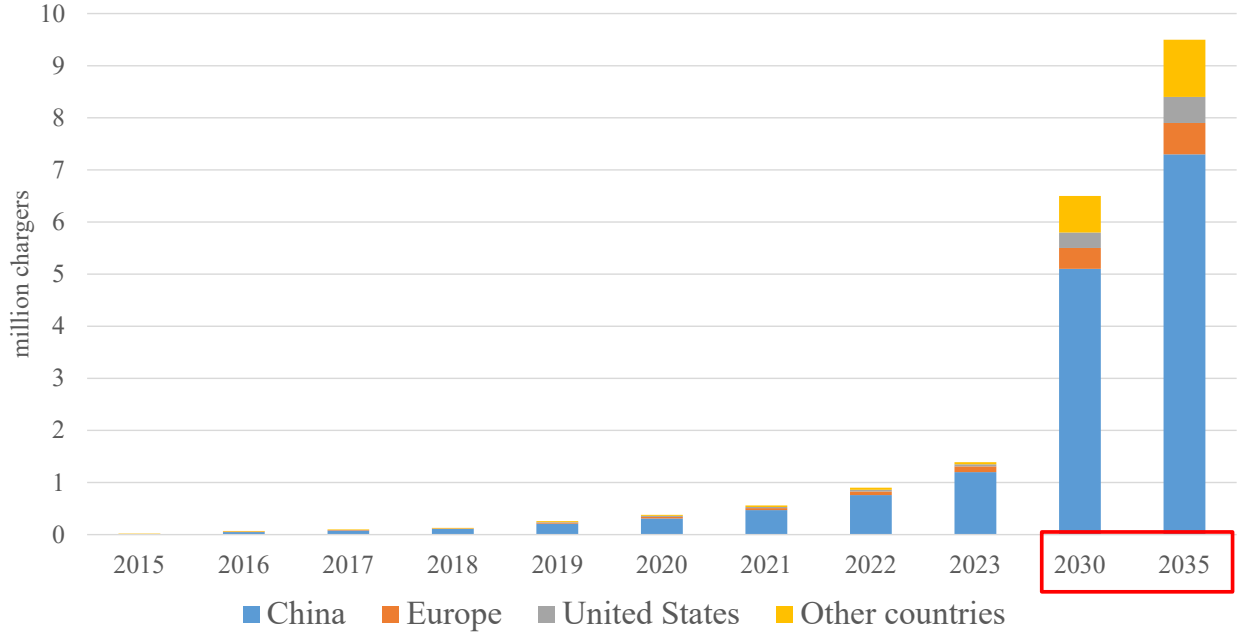
- Europe: By 2023, the European charging station market has grown rapidly from about 10,000 locations in 2012 to 500,000. The European Union is aiming for 3.5 million charging points by 2030. Strengthening is required to meet the electricity demand of this new EV infrastructure.

- North America: In the United States, about 6,300 rapid chargers were installed in 2022, approximately 75% of which are Tesla Superchargers. The U.S. government is targeting 500,000 public EV charging ports by 2030.

- Asia: China has made significant investments in public charging infrastructure, accounting for over 85% of the world's rapid chargers. The Chinese government aims for 60% of EV charging to occur during off-peak hours by 2025.

3 The Evolution of Charging Infrastructure and Global Trends

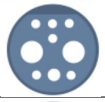
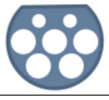
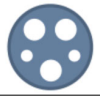
Publicly installed accessible charging points by fast chargers and region



Source: Outlook for electric vehicle charging infrastructure （IEA）
https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-electric-vehicle-charging-infrastructure
Trends in electric vehicle charging (International Energy Agency: IEA)
https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-vehicle-charging

4. Charging Method

4. Charging Method

Standards	Charging speed (maximum)[kW]	Charging time (approximate) [min]	Connector type
ChaoJi	900 (Scheduled)	10	
CCS	350	15	
Tesla Supercharger	250	20	
GB/T	250	20	
CHAdeMO	50	40	
Type 2	22	300	
Type 1	7.2	480	

Source: Created by the expert team based on various sources,
Connector type: EV Adoption Saves Stable Power Supply: Session 1 – Charging Connectors & Communication Standards (Mitsubishi Research Institute)
EV普及が電力の安定供給を救う　第1回：充電コネクター・通信規格（三菱総合研究所）
https://www.mri.co.jp/knowledge/column/20230912.html

4. Charging Method

- Major Charging Connector Standards

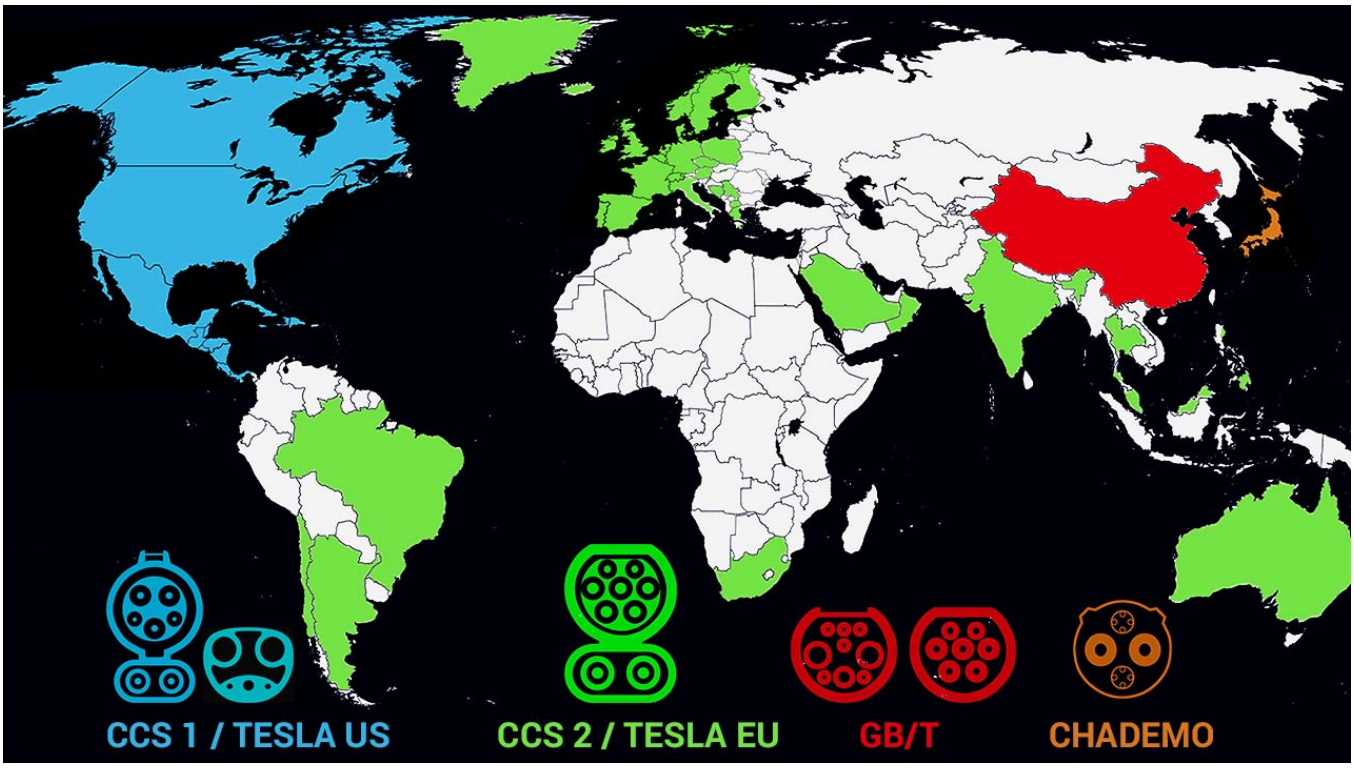
➢ CHAdeMO: A rapid charging standard originating from Japan. It supports V2G (Vehicle-to-Grid), allowing bidirectional energy exchange between EVs and the power grid.

➢ CCS (Combined Charging System): The mainstream standard in Europe and North America. It supports both AC and DC charging, offering high versatility and is widely adopted by major automakers.

➢ GB/T: A unique standard in China, typically used in EVs in the Chinese market. It has a high adoption rate within China and is increasingly influencing the international market.

4. Charging Method

- Major Charging Connector Standards



Source: EV Charging Plug types for Electric Car Charging （MIDA）
https://www.midaevse.com/project/ev-charging-plug-types-for-electric-car-charging/

5. Smart Charging Technology

5. Smart Charging Technology

■ V1G

A smart charging technology that allows control over the timing and speed of EV charging based on the status of the power grid and energy demand.

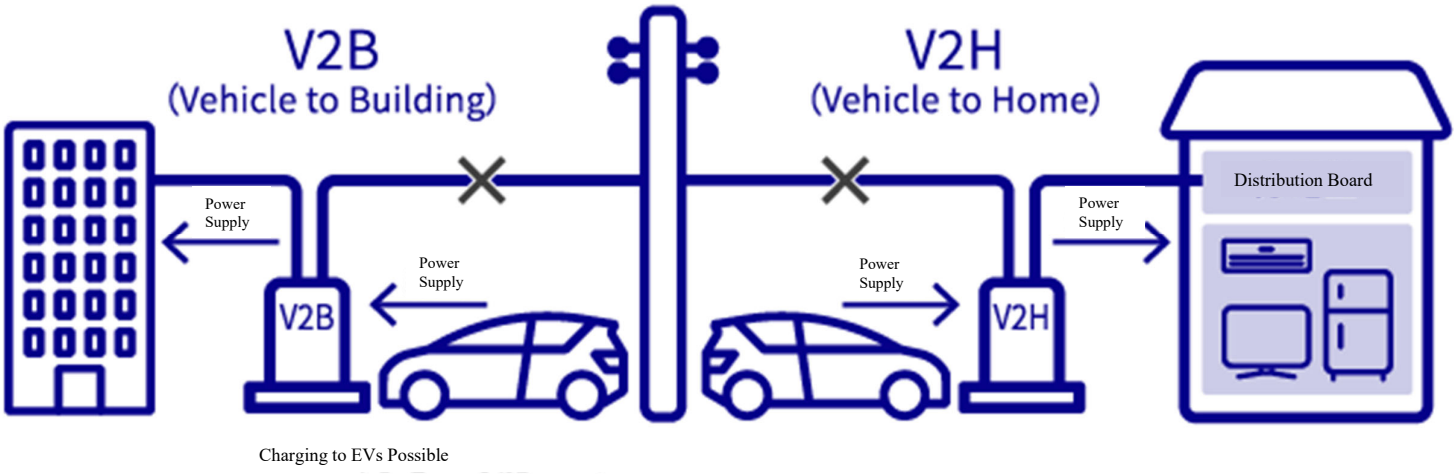
■ V2G

A technology that enables bidirectional energy exchange with the power grid, allowing EVs to supply stored electricity back to the grid. This contributes to peak shifting and the effective utilization of renewable energy.



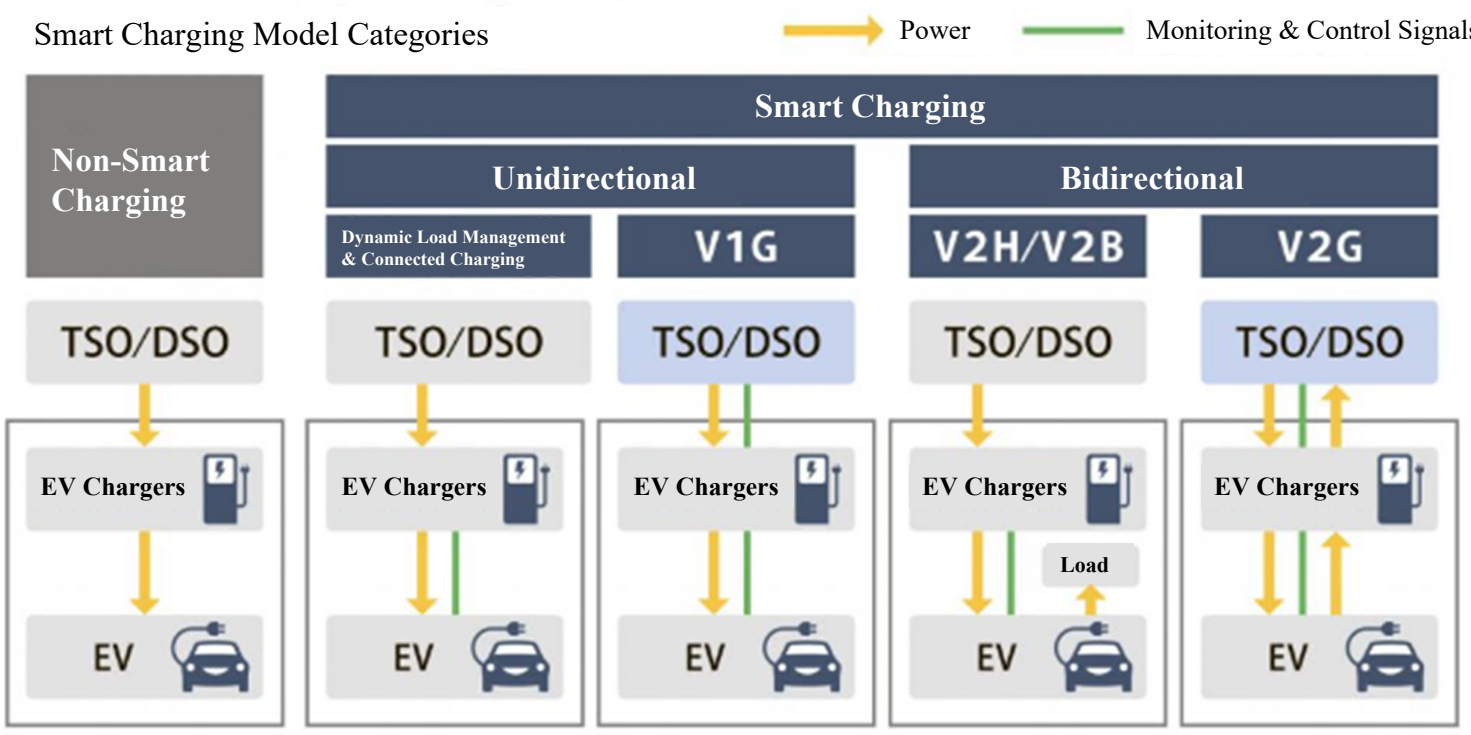
Source: Blockchains for Electric Vehicles & Grid Integration Review（Mobility Open Blockchain Initiative） https://dlt.mobi/wp-content/uploads/2020/10/EVGI-Business-Review.pdf

5. Smart Charging Technology



Source: Next-Generation Mobility: EVs in Emergencies (Japan Car Solutions)
次世代モビリティ　非常時におけるＥＶ（日本カーソリューションズ）
https://www.ncsol.co.jp/solution/emergency-ev/index.html

5. Smart Charging Technology



Source: UK Venture Commercializing Smart Charging Including V2G. One-stop EV Implementation (Electric Newspaper Digital)
Ｖ２Ｇ含むスマート充電を商業化する英ベンチャー。ＥＶの導入もワンストップで（電気新聞デジタル）

5. Demand Control Charging Method

Demand Control Charging Method is a charging approach that controls the charging current to remain below a preset demand level to prevent increased contract power costs due to demand excess.

Mechanisms

- Utilization of real-time electricity supply and demand data
- Control signals from power companies or aggregators
- Dynamic adjustment of EV charging power and timing

Benefits

- Stabilization of the power grid
- Effective utilization of VRE
  (Fluctuation control, power outage measure, Peak shifting/cutting etc.)
- Reduction in capital investment through peak cutting and peak shifting

5. Other Smart Charging Technologies

Peak Shifting and Demand Response

- By charging during off-peak times, the burden on the grid is reduced. This improves the stability of power supply and enables a reduction in energy costs.

Charging Based on Time-of-Use Rates

- By charging during times when electricity rates are lower, EV owners can reduce their electric bills.
- Reducing power demand during peak times can lead to overall energy cost savings.

Integration with Renewable Energy

- By charging during times when the generation of renewable energies such as solar and wind is high, the use of renewable energy is maximized. This can lead to a reduction in CO2 emissions.

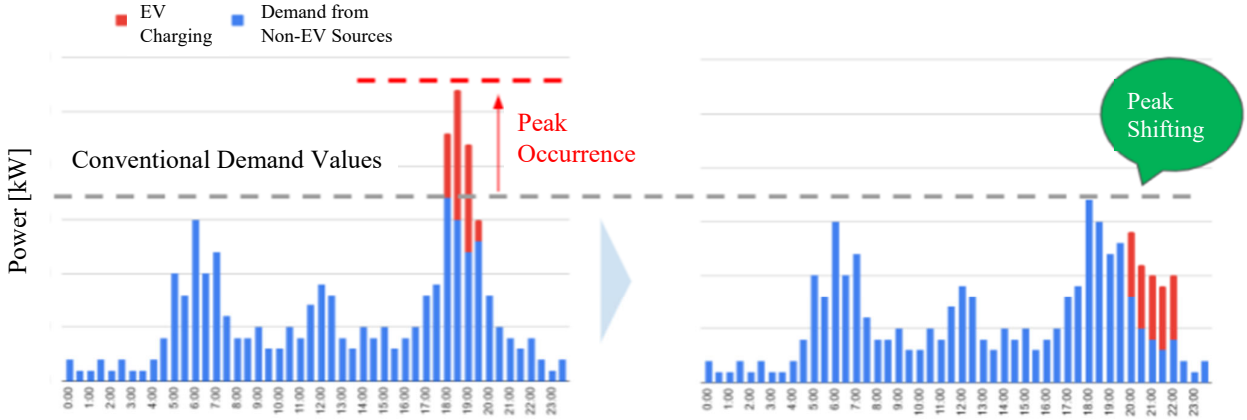
6. Case Studies in Japan

6. Case Studies in Japan

■ Peak Shifting and Demand Response for EVs Used in Postal Collection and Delivery

➢ The timing of charging for EVs used in collection and delivery was automatically controlled via the cloud to avoid coinciding with power peaks, which occurred in the evening when vehicles returned to the post office.

EV Charging Peak Shifting Image

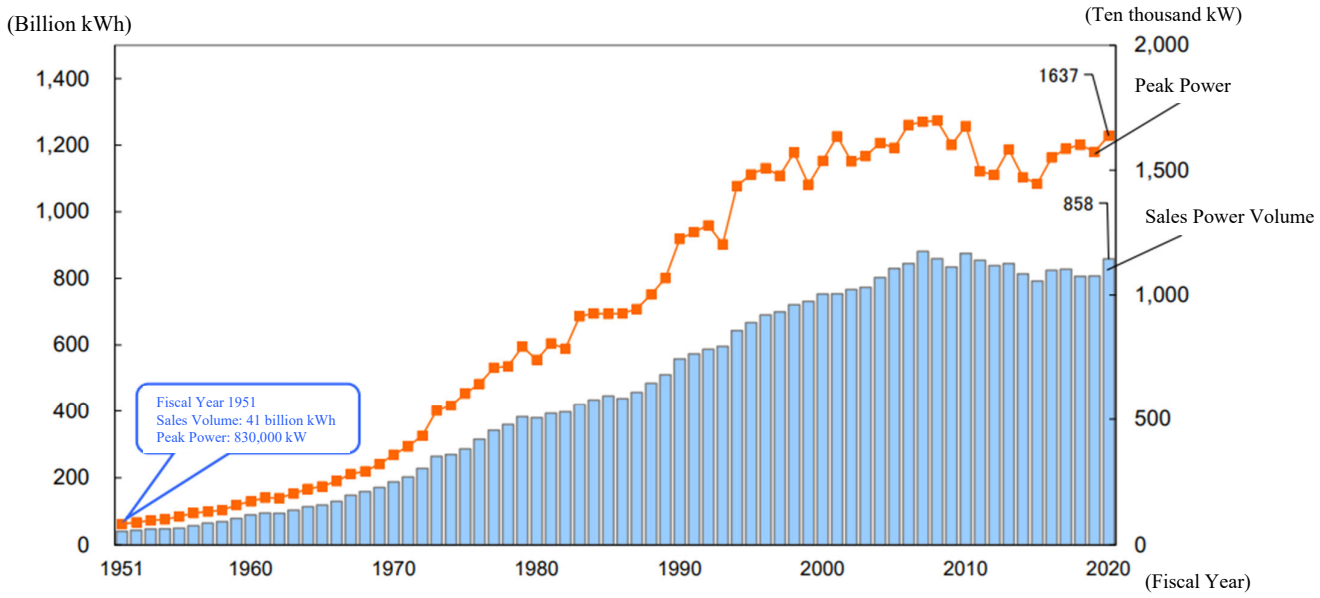


Source: Charging Control for Electric Vehicles (EVs) Curbs Power Peaks! Post Offices Tackle the "Electricity Supply and Demand Tightness Issue" (Japan Post Group)
電気自動車（EV）の充電制御で、電力ピークを抑制！「電力需給ひっ迫問題」に郵便局が取り組む（日本郵政グループ）
https://www.jpcast.japanpost.jp/2023/03/337.html

6. Case Studies in Japan

■ Kyushu Electric Power's Sales Volume and Peak Power

In the fiscal year 2020, Kyushu Electric Power's sales volume was 858 billion kWh, and the peak power in the Kyushu area was 16.37 million kW.



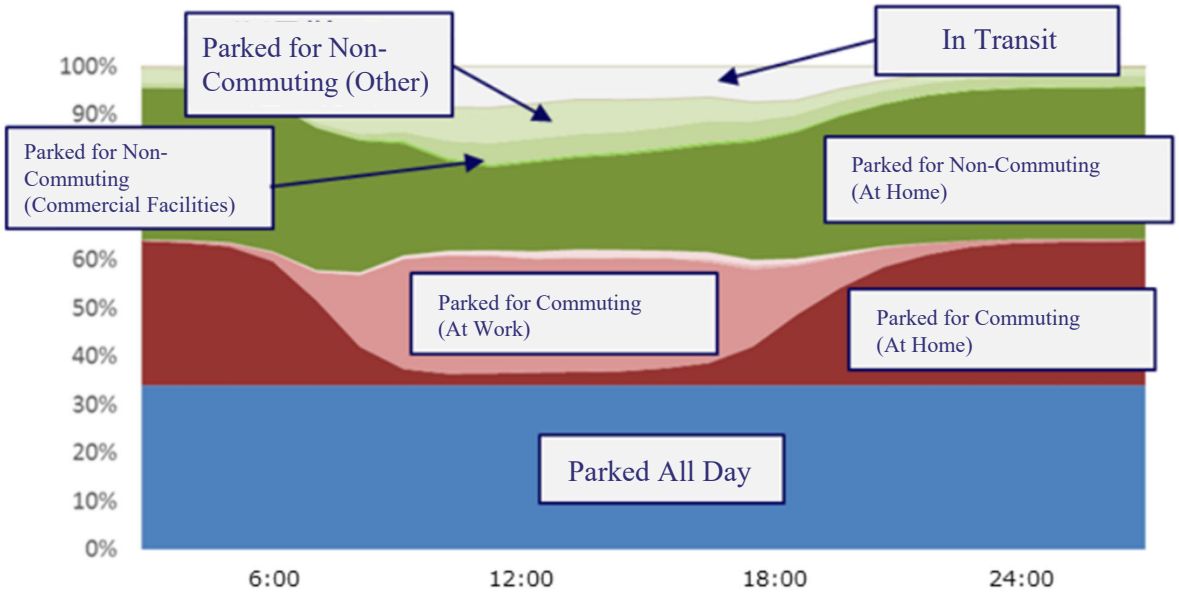
Source: Kyuden Group Data Book 2021
九電グループデータブック 2021
https://www.kyuden.co.jp/var/rev0/0364/5488/data_book_2021_all_c.pdf

6. Case Studies in Japan

■ V2G Pilot Experiment

➢ A survey was conducted in Fukuoka Prefecture to determine where and when gasoline vehicles are parked. It was found that 95% of vehicles are parked somewhere at any given time, suggesting that if all vehicles were converted to EVs, a vast amount of EV batteries could potentially be used in grid operations.

Time Variation of Passenger Car Parking Numbers on Weekdays in Fukuoka Prefecture



Source: Lecture 3: Evaluating the Potential of VPP Business through EV Aggregation (The Institute of Electrical Engineers)
講演3　EVアグリゲーションによるVPP事業の可能性評価（電気学会）
https://www.iee.jp/pes/zadan-03/

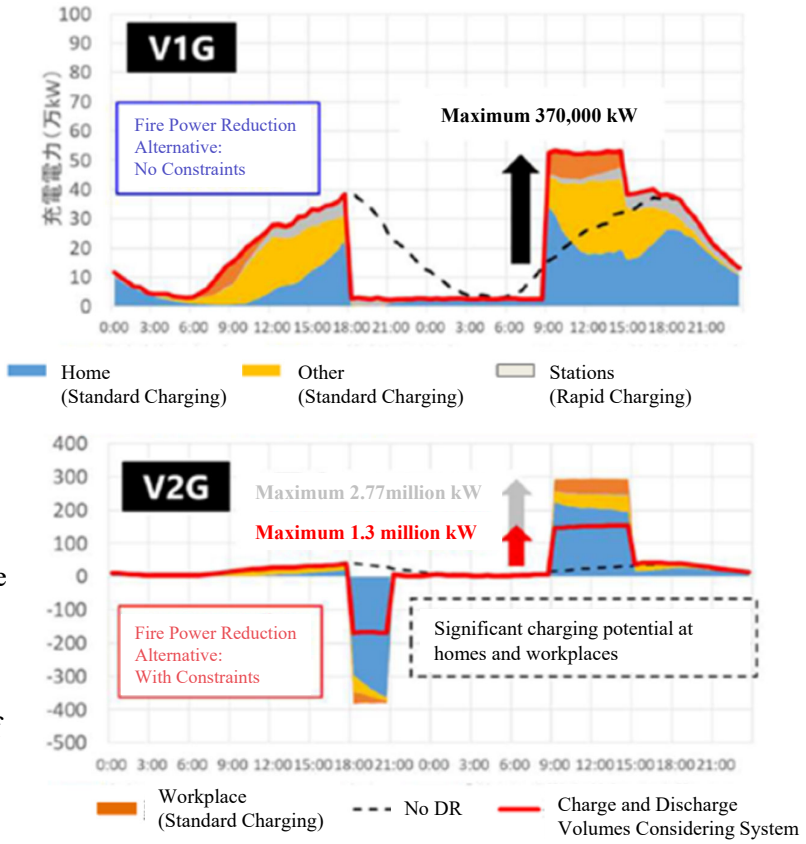
6. Case Studies in Japan

■ V2G Pilot Experiment

- ➢ A simulation was conducted in the Kyushu area, assuming the adoption of 1.2 million EVs, to evaluate the potential of increasing daytime demand using V1G and V2G by analyzing driving routes and charging times.
- ➢ The results showed that V1G could increase demand by 370,000 kW, and V2G could increase demand by 1.3 million kW.

- ● V1G: Shifts EV charging volume after 6 p.m. to the next day's daytime hours (9 a.m. to 3 p.m.) to create demand.
- ● V2G: In addition to V1G, discharges between 8 a.m. and 9 p.m., securing space in the EV's state of charge (SOC). This space is then charged between 9 a.m. and 3 p.m. the next day to create demand.

Two-Day Simulation (V1G, V2G: 100% Connection Rate)

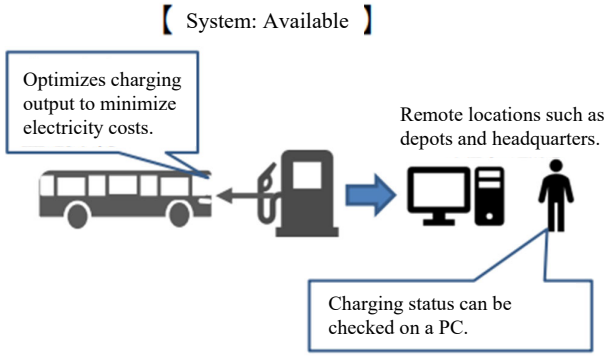


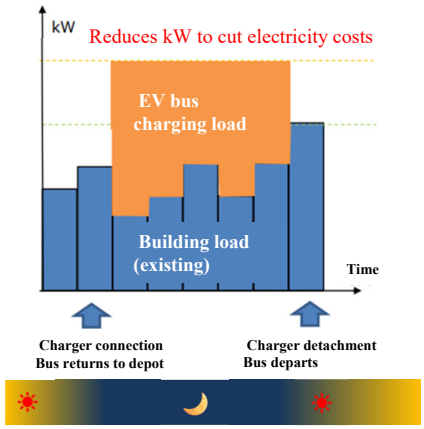
Source: Lecture 3: Evaluating the Potential of VPP Business through EV Aggregation (The Institute of Electrical Engineers)
講演3　EVアグリゲーションによるVPP事業の可能性評価（電気学会）

6. Case Studies in Japan

■ Charging Management System for Bus Companies

- ➢ A system that smoothly handles overnight charging for multiple EV buses.
- ➢ Automatically controls charging to minimize electricity costs for EV bus charging.
- ➢ Optimizes charging to ensure full charge by departure time.





Source: Utilization of EVs in Power Systems (Tokyo Electric Power Company Holdings, Inc.)
EVの電力系統での活用について（東京電力ホールディングス株式会社）
https://www.emsc.meti.go.jp/activity/emsc_localdemand/pdf/0001_06_00.pdf

Presentation Material 2- 2

Activity 2-2-1 Benchmark on the Impact on the Power Distribution System Including Case Study in Japan

Benchmark on the Impact on the Power Distribution System Including Case Study in Japan

Activity 2-2-1

JICA Expert Team

September 2024

Japan International Cooperation Agency
Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

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2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

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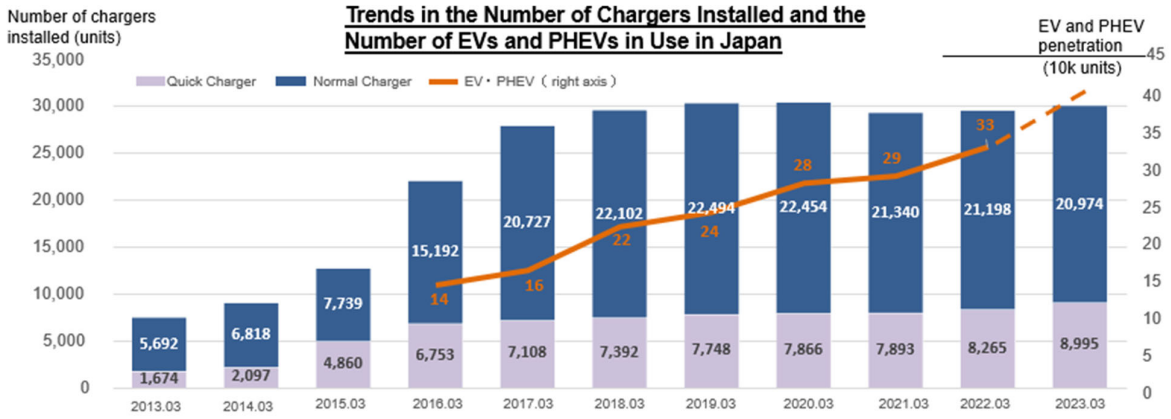
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1. Positioning of EV in Japan's CN Goals

1.Positioning of EV in Japan's CN Goals

- The Japanese government has formulated a “Green Growth Strategy” led by the Ministry of Economy, Trade and Industry (METI) to achieve carbon neutrality by 2050. The strategy includes a target of 100% electric vehicles in new car sales by 2035, and the number of EV (BEV) and PHEV is expected to increase in the future.
- In October 2023, METI announced “Guidelines for Promoting the Development of Charging Infrastructure,” setting a target of 300,000 rechargers by 2030, including 30,000 quick rechargers for public use.



Source: METI Initiatives to Promote the Development of Charging Infrastructure、2024

2. EV Charging Facilities in Japan

2.EV Charging Facilities in Japan

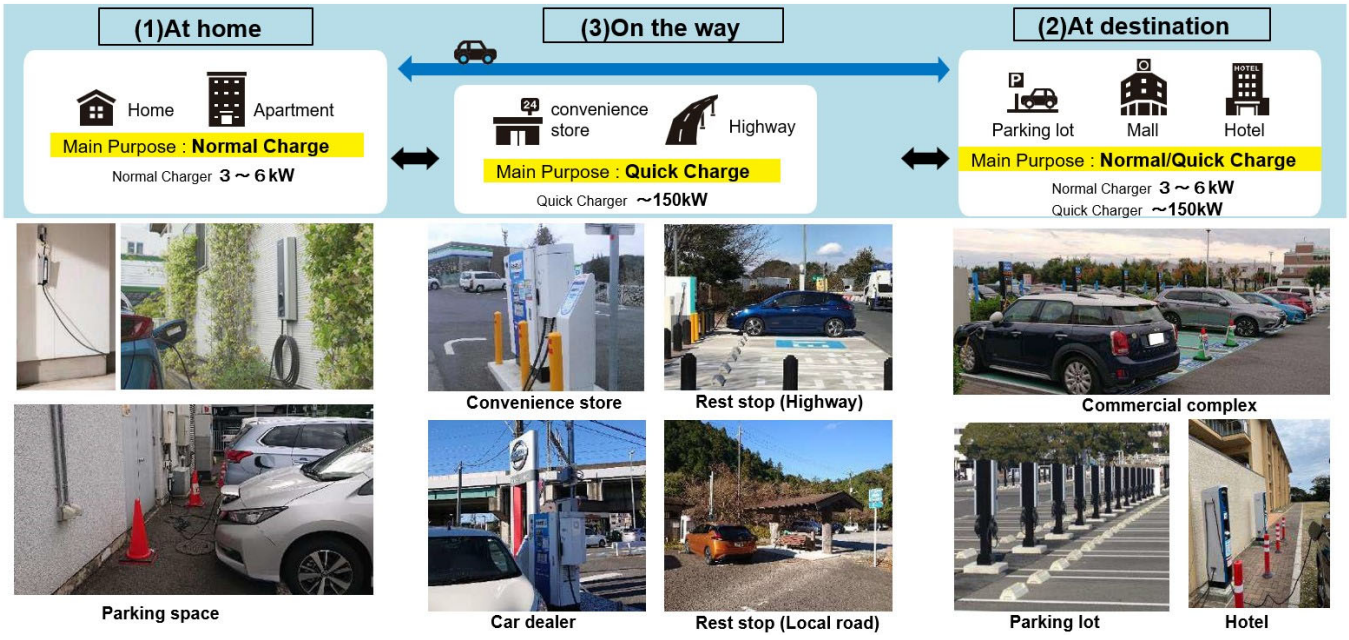
- The types of chargers range from 3-6 kW for normal chargers to over 90 kW for quick chargers. In particular, the output of quick chargers is expected to increase to over 150 kW in the future.
- The impact on the power system from the expansion of charger installation needs to be considered according to the type of use.

Type of Charger	Normal Charger		Quick Charger	
				
Output power	3~4kW	3~6kW	50kW	90kW
Socket		 IEC62196-2 Type 1（SAE J1772）	 CHAdeMO	
Type of current	Power source: AC, single-phase (100V, 200V) Output: AC, single-phase (100V, 200V)		Power source: AC, three-phase (200V to 460V) Output: DC (200V to 450V)	

Source: METI Initiatives to Promote the Development of Charging Infrastructure,2023

2.EV Charging Facilities in Japan

- Depending on how cars are used in Japan and EV charging needs, the recharging infrastructure can be divided into three objectives
  (1) Charging at home
  (2) Charging at destination
  (3) Charging on the way (mainly long-distance travel)

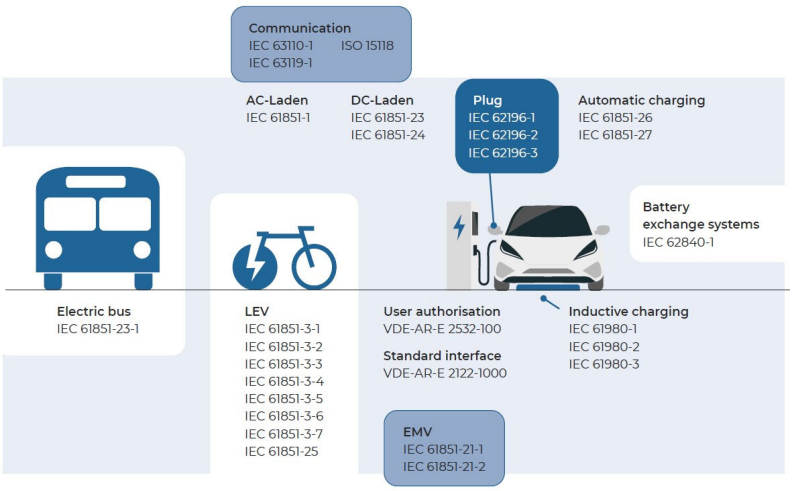


Source: METI: Initiatives to Promote the Development of Charging Infrastructure,2024

3. Global Connection Standards for IRVE Integration

3. Global Connection Standards for IRVE Integration

- Overview of global connection standards for IRVE integration
  - EV charging standards ensure compatibility, safety, and efficiency. They define technical specs, communication protocols, and connectors for charging stations, enabling vehicles from different manufacturers to use the same infrastructure.
  - These standards facilitate safe, efficient charging, promote interoperability, and encourage competition among charging infrastructure providers, aiding in the adoption of electric vehicle
- Key standards include:
  - SAE (North America, Europe): SAE J1772 (AC) and SAE Combo (CCS) for both AC and DC charging.
  - IEC (Global): IEC 61851 for AC and DC charging, with IEC Type 2 connectors in Europe.
  - CHAdeMO (Japan): Supported by multiple international manufacturers.
  - GB/T (China): Widely used within China.



Overview of relevant norms and standards in the field of charging of electric vehicles.

Source: Source: Technical Guideline, Charging Infrastructure Electromobility, Ver. 4, BDEW, DKE, VDA, VDE FNN, ZVEH, ZVEI, 2022.

4. IRVE Charging Infrastructure and Grid Integration

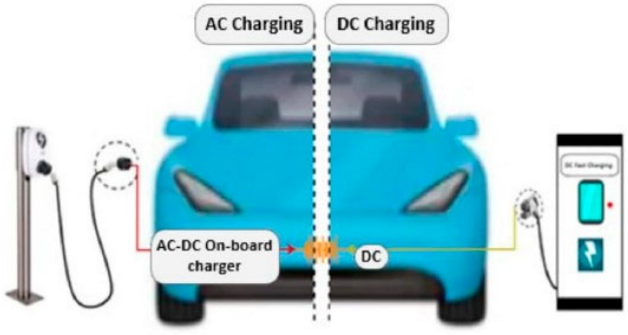
4. IRVE Charging Infrastructure and Grid Integration

- Converting AC to DC simplifies battery charging.
  - As illustrated in the figure, there are two primary types of charging systems: AC and DC. Other classifications are based on the type, location, and power flow between EVs and IRVEs.
  - According to the Society of Automotive Engineers (SAE) and IEC standards, this charging infrastructure is categorized into three distinct types, which are as follows.

Classification of different types of EV charging systems

EV Charging System			
Types of Power	Accommodation of Charging Circuit	Physical Contact	Direction of power Flow
AC, DC	On-board, Off-Board, Warless	Conductive, Inductive Wireless	Unidirectional, Bidirectional

Source: Distributed Energy Resources and Electric Vehicle Analysis and Optimisation of Network Operations, Electric Vehicle Charging Infrastructure Optimal Location Problem: Modeling Options and Solution Techniques, Dil Khush Meena et al.



Illustrated on-board/off-board EVs fast charging.

Source: A Comprehensive Review of Developments in Electric Vehicles Fast Charging Technology, Appl. Sci., A. Zentani et al., 2024.

4. IRVE Charging Infrastructure and Grid Integration

- Charging methods for steady-state studies of EV integration in the electrical power distribution system are currently being adopted to address various charging needs and infrastructure requirements, each involving distinct power levels
- The deployment of EVs will significantly impact the management and operation of distribution grids. The additional power demand from EVs will require Disco's to understand the effects of integrating EVs into distribution networks, various strategies have been explored to address these challenges.
- Several types of EV charging solutions are currently in use, each addressing different charging needs and infrastructure requirements with varying power levels. Here are some common charging models:

  - Level 1: Provides around 3 kW of charging power through standard domestic outlets.
  - Level 2: Offers 10–20 kW of charging power via dedicated charging outlets and wiring.
  - Level 3: Delivers over 40 kW of charging power through dedicated charging outlets, wiring, and off-board DC fast chargers.

4. IRVE Charging Infrastructure and Grid Integration

- Level 1 is typically classified as slow charging, while Level 3 is considered fast charging. Level 2 serves as an intermediate option, which can be categorized as either slow or fast charging depending on context.
- Generally, slow charging corresponds to Level 1, and fast charging includes both Level 2 and Level 3.

Comparative Analysis of Charging Levels

Type	Charging Type	Input Voltage, Current	Charging Time	Power rating (KW)	Charging Standard
Level 1 (AC)	On-board	110 V, 15 A	10-13 Hr	1.4-1.9 KW	SAE, IEC
Level 2 (AC)	On-board	240 V, 40 A	1-1 Hr	19.2 KW	SAE, IEC
Level 3 (AC)	On-board	400-500 V 80 A	0.5-1.4 Hr	> 20 KW	SAE
Level 1 (DC)	Off-board	200-450 V, 80 A	1.2 Hr	36 KW	SAE, CHAdeMO
Level 2 (DC)	Off-board	200-450 V, 200 A	0.4 Hr	90 KW	SAE, CHAdeMO
Level 3 (DC)	Off-board	200-600 V, 400 A	0.2 Hr	240 KW	SAE, CHAdeMO

Source: Distributed Energy Resources and Electric Vehicle Analysis and Optimisation of Network Operations, Electric Vehicle Charging Infrastructure Optimal Location Problem: Modeling Options and Solution Techniques, Dil Khush Meena et al.

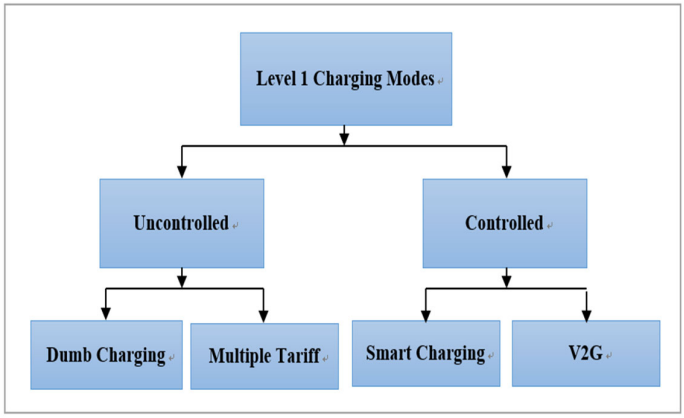
5. Impact of Dumb Charging on Power Distribution

5. Impact of Dumb Charging on Power Distribution

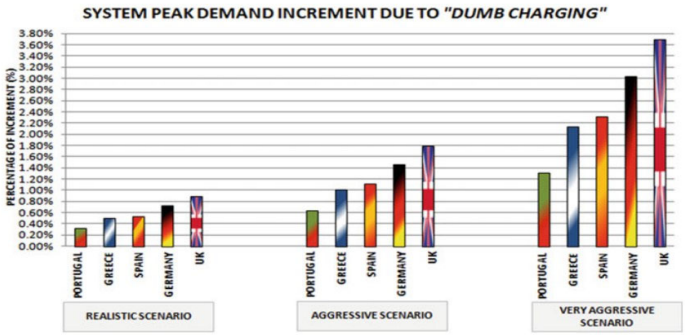
- **Dumb Charging :**
  - Dumb Charging at Home: This scenario involves connecting the EV to the home grid only after the last trip of the day and assumes that the vehicle is charged when the owner returns home, typically with a single connection point.
  - Dumb Charging at Workplace Chargers: In this scenario, the EV owner has the option to charge their vehicle at alternative locations, such as a workplace charger.
  - Dumb Charging with Battery SOC Threshold: This scenario considers a situation where a significant portion of the EV fleet uses only a small fraction of battery capacity each day. It examines cases where EV owners charge their vehicles when the state of charge (SOC) drops below 40%.
- **Multi-Tariff Scheme:**
  - Various energy providers offer different tariff plans in the market. While it is challenging to represent all low tariff signals with a single pattern, many providers offer reduced rates during specific periods, such as from 22:00 to 06:00 in winter or summer.

5. Impact of Dumb Charging on Power Distribution

- The figure illustrates the additional charging demand for the three penetration scenarios across five European countries. When comparing peak EV demand for smart charging with previous charging methods, it is evident that the peak demand during smart charging is roughly one-fourth of that during dual-tariff charging but higher than the peak observed with dumb charging.
- Nonetheless, smart charging effectively distributes the EV demand across off-peak hours, enhancing the system load factor.



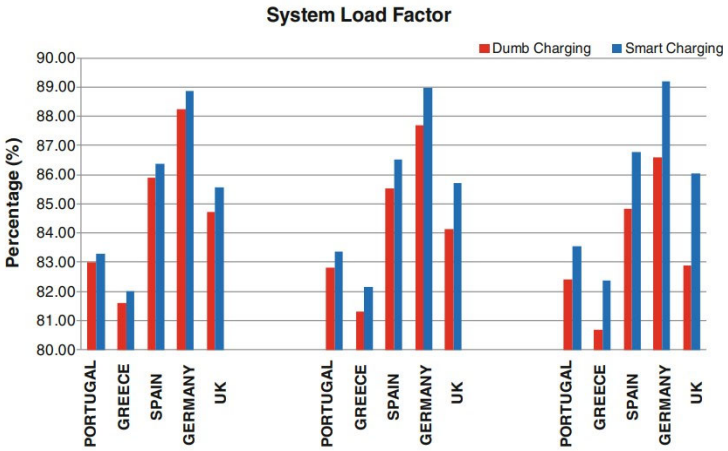
Source: Electric Vehicle Integration into Modern Power Networks, Advanced Models and Simulation Tools to Address EV Power System Integration (Steady-State and Dynamic Behavior), F.J. Soares et al.



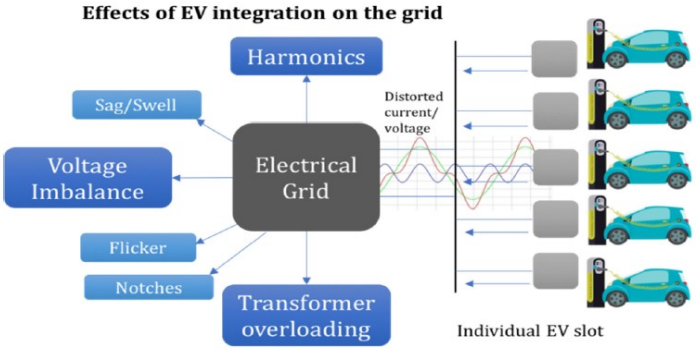
Source: Electric Vehicle Integration into Modern Power Networks, The Impact of EV Charging on System Demand, N. Hatziargyriou et al.

5. Impact of Dumb Charging on Power Distribution

- The analysis reveals that additional energy for EV charging affects the daily and annual system demand, with "dumb charging" potentially causing peak load issues and local network congestion.
- Developing workplace charging can mitigate these impacts by distributing demand more evenly throughout the day.
- Dual-tariff charging is more effective than dumb charging, as it shifts EV demand from peak to off-peak hours, reducing system load variation, though its implementation requires advanced control and management techniques.



Source: Electric Vehicle Integration into Modern Power Networks, The Impact of EV Charging on System Demand, N. Hatziargyriou et al.

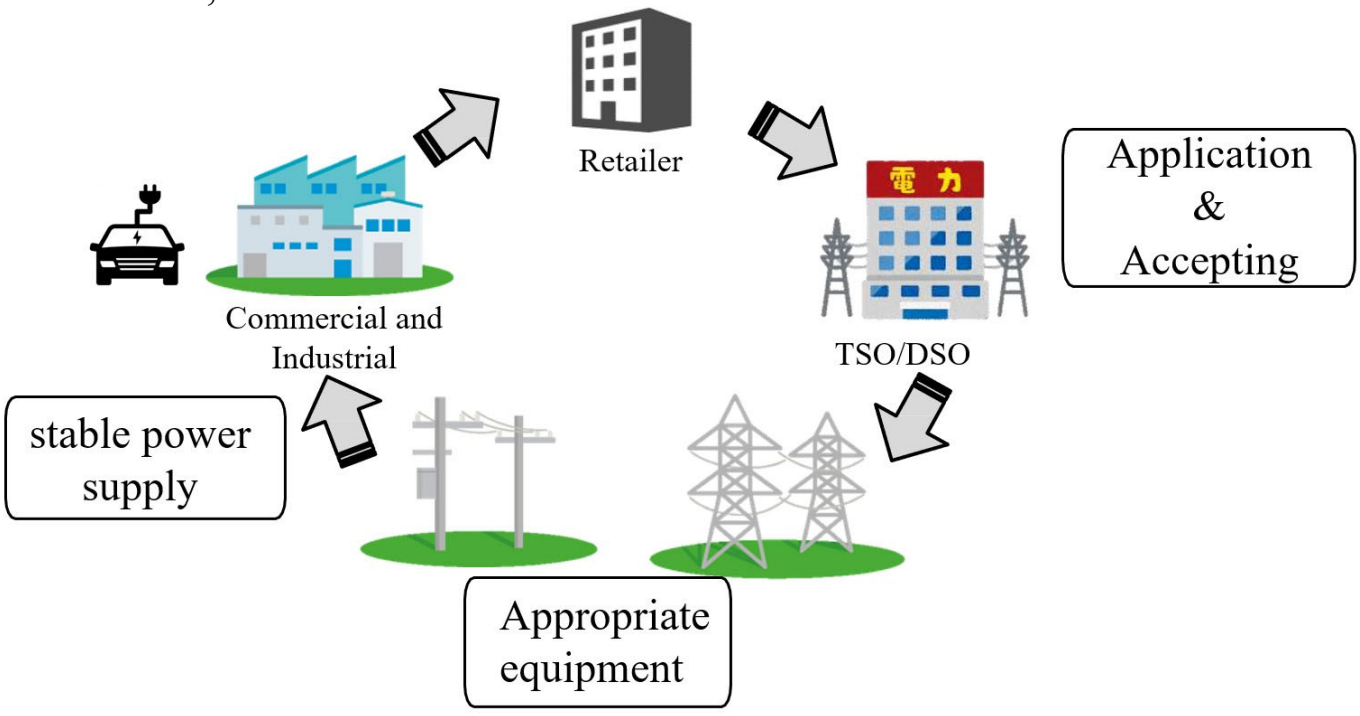


Source: DOI: 10.1016/j.epsr.2023.109899

6. Power Distribution System: Best Practices in Japan

6. Power Distribution System: Best Practices in Japan

- Flow of Supplying Electricity to EV Charging Facilities
- The power supply to the quick chargers is based on the necessary grid measures, which are discussed in advance with the TSO/DSO.

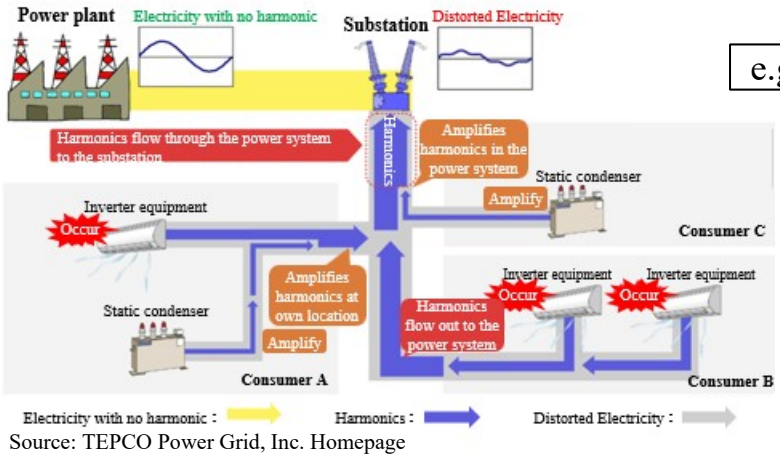


Source: TEPCO Power Grid, Inc. Homepage

6. Power Distribution System: Best Practices in Japan

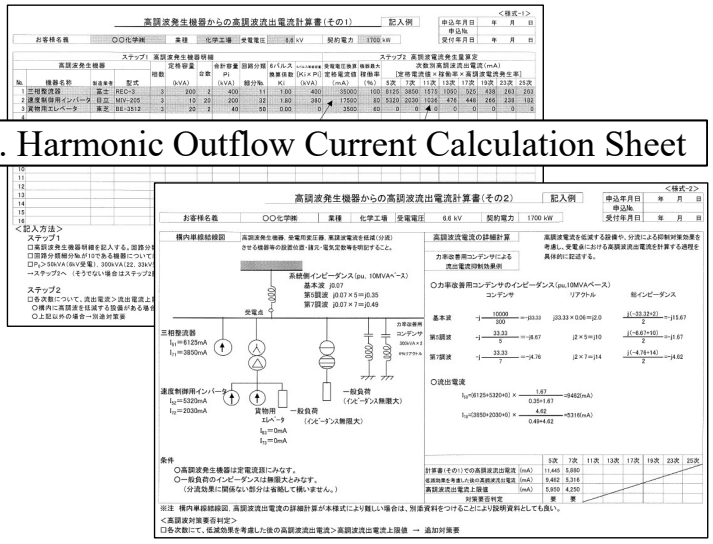
- Technical Guideline for Harmonic Suppression Measures
- The Japan Electric Association (JEAG) issued JEAG 9702, a technical guideline for harmonic suppression measures, in order to suppress disturbances to other electrical equipment caused by harmonic currents generated by electronic equipment.
- High-voltage consumers are required to prepare and submit harmonic outflow current calculations to DSO/TSO in accordance with the guidelines.

Mechanism and Effects of Harmonics Generation



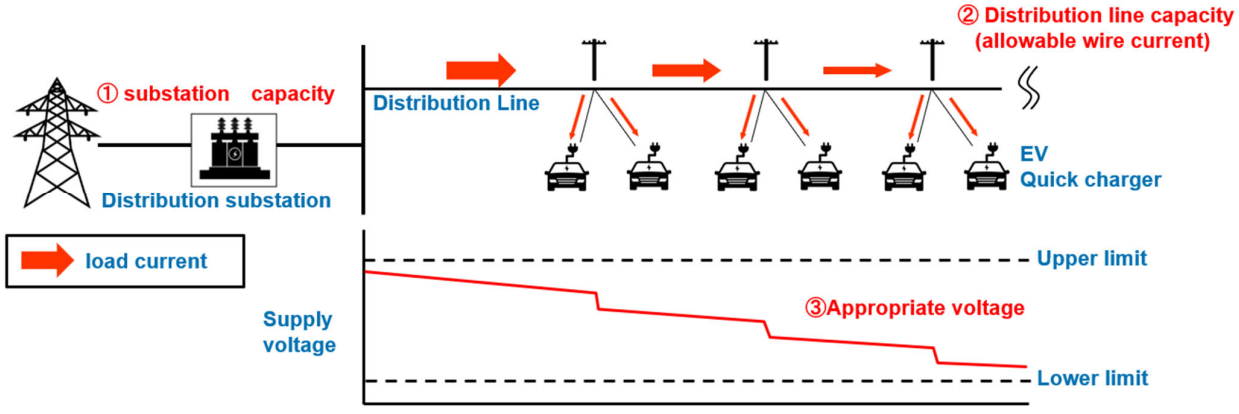
Source: TEPCO Power Grid, Inc. Homepage

e.g. Harmonic Outflow Current Calculation Sheet



6. Power Distribution System: Best Practices in Japan

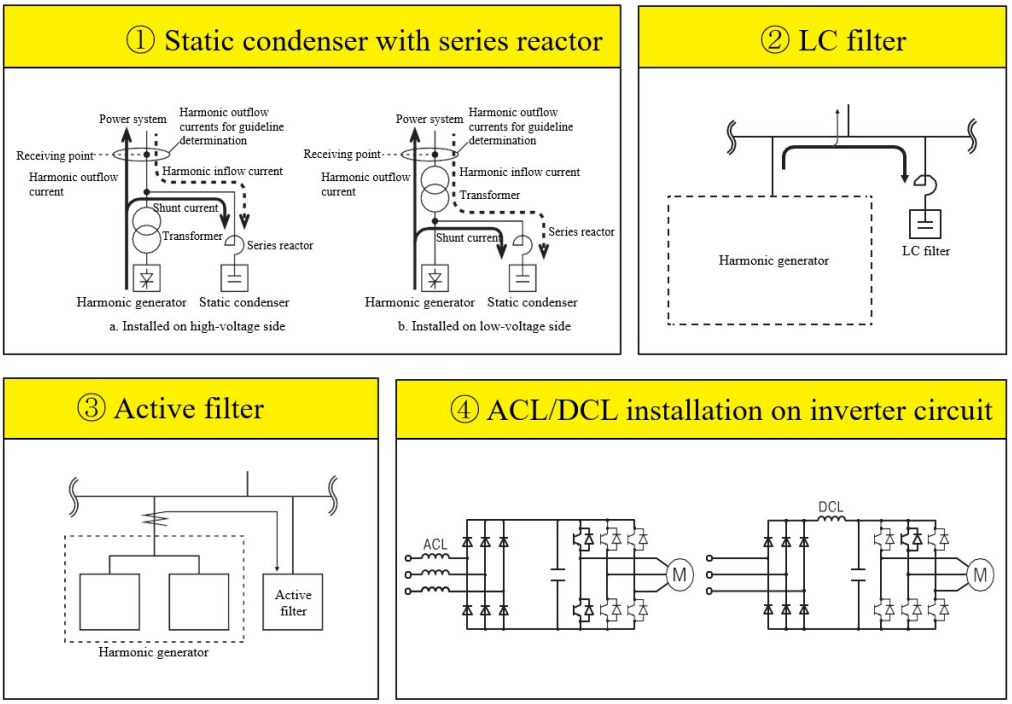
- With the connection of quick chargers to the power distribution system, TSO/DSO examines whether the facility capacity is exceeded or not(①②), and whether there are voltage deviations or not(③).
- If measures are required for the distribution system, they shall be developed in the following order, taking economic efficiency into consideration.
  a. Load switching between distribution lines
  b. Converting distribution lines to larger lines
  c. Construction of new distribution lines



Source: JICA Expert Team

6. Power Distribution System: Best Practices in Japan

- Harmonic Suppression Measures
- If the harmonic currents flowing into the distribution system exceed the upper limit, the high-voltage consumer must take the following measures

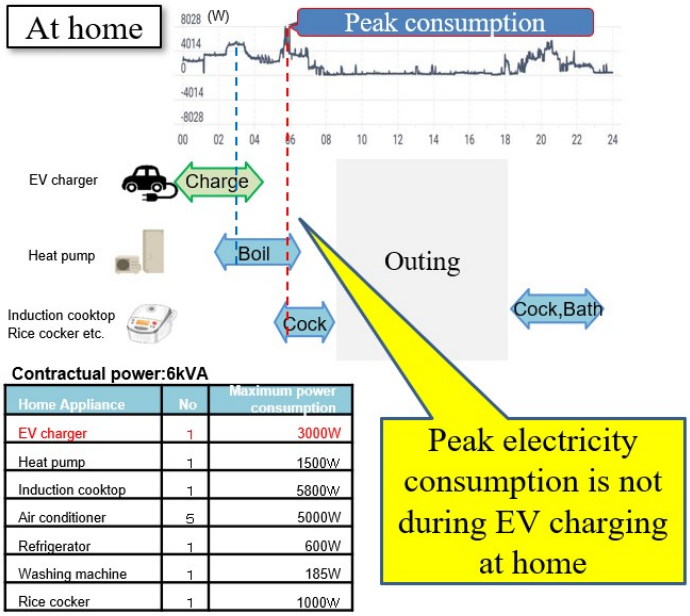


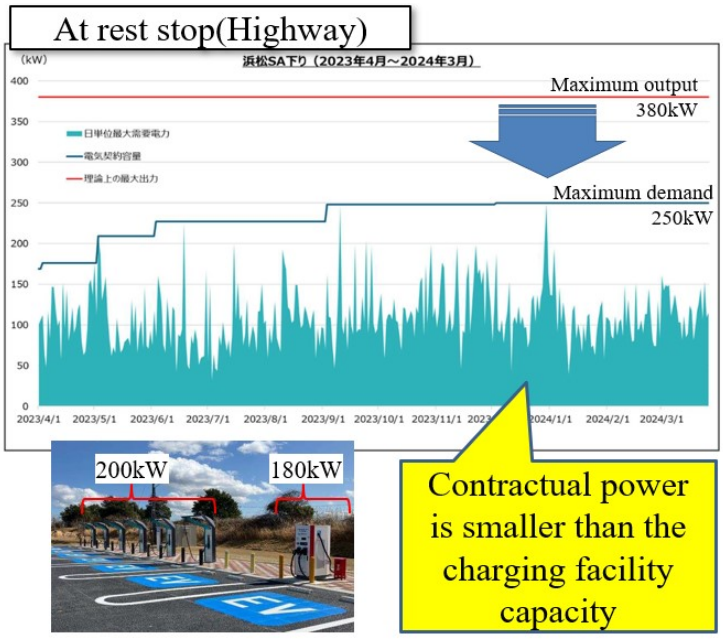
Source: The Japan Electrical Manufacturers' Association, Inc.: Harmonics suppression measures, 2019

7. EV Charging Behavior: Japan vs. Other Countries

7. EV Charging Behavior: Japan vs. Other Countries

- Many users of normal chargers at ordinary residences charge during off-peak hours to reduce basic rate.
- At quick charging spots on highway, there are few cases of vehicles with high-capacity batteries charging at the same time, so demand tends to be lower than the maximum output of the charging facilities.





Source: e-Mobility Power: EV charging situation and challenges in Japan, 2024

7. EV Charging Behavior: Japan vs. Other Countries

- According to the IEA, EV charging facilities will not cause any impact on the power transmission and distribution network in most countries at this time.
- On the other hand, Norway and other countries are experiencing significant changes in EV demand, and measures such as shifting the timing of recharging are being taken.

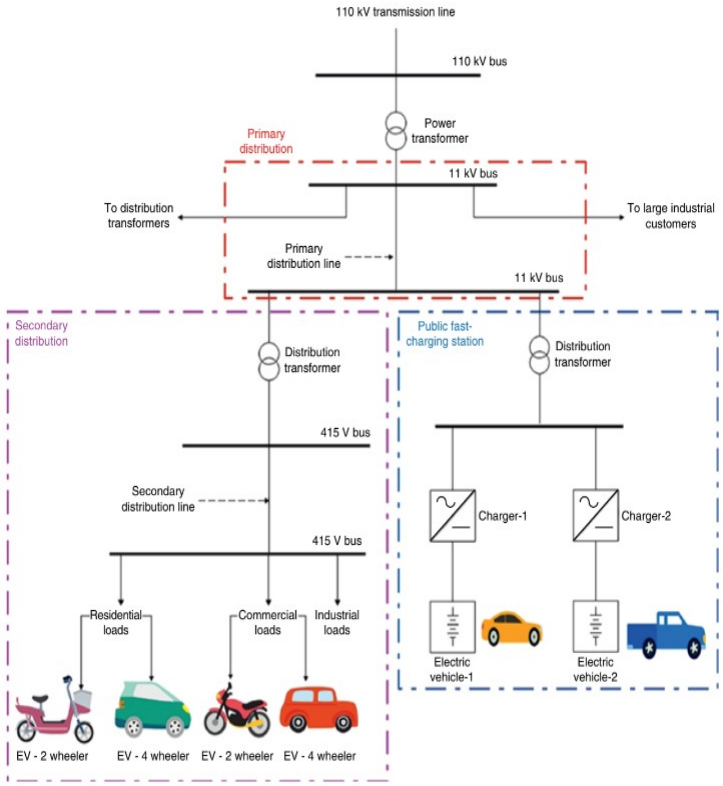
PHASE 1: No noticeable impact	**PHASE 2: EV load noticeable with low flexibility demand**	**PHASE 3: Flexible EV load is significant with high flexibility demand**	**PHASE 4: Flexible EV load is highly available with high flexibility demand**
No significant impact yet. Encourage higher EV uptake through incentives and public EVSE deployment.	Distinct variability observed caused by EV charging but demand for flexibility is low enough that simple flexibility measures would suffice.	Demand for flexibility is high, matching the availability of flexible EV load and paving the way for aggregated smart charging.	High flexibility demand along with highly available flexible EV load can provide energy back to the system in periods of deficit.
Co-ordinate charging station deployment in areas beneficial to the grid	**Passive measures:** time-of-use tariffs, vehicle-based charging time delays	Deploy active measures: unidirectional V1G	Deploy active measures, bidirectional charging: V2G
Most countries today	**Norway**	**France, Netherlands, United States**	**Island power systems, certain vehicle segments**

Source: IEA (2022), Grid Integration of Electric Vehicles

8. Impact of IRVE Expansion on Distribution Grid

8. Impact of IRVE Expansion on Distribution Grid

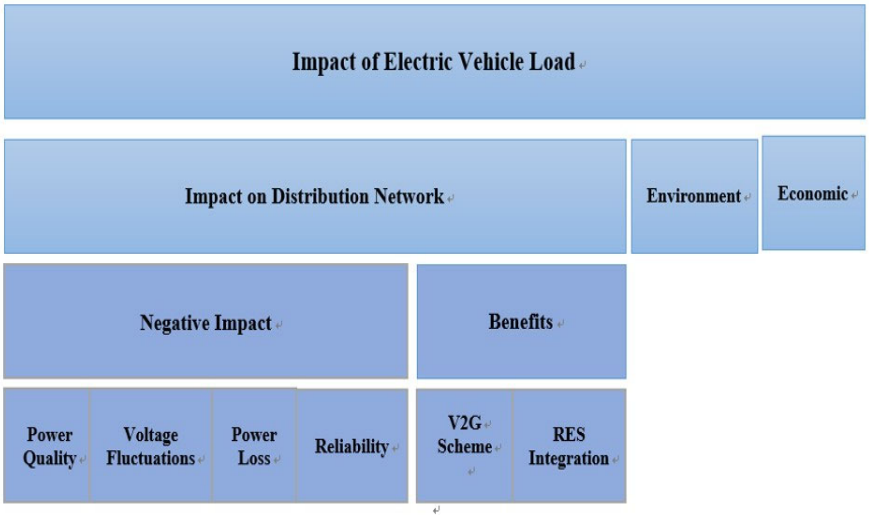
- The rapid global expansion of the EV market presents new challenges for distribution networks and their operators.
- While level 1 chargers consume about 3 kW and have minimal impact on the grid, level 3 chargers can demand up to 100 kW, potentially straining the grid.
- Excessive high-power chargers can negatively affect bus voltages, power efficiency, and system stability.



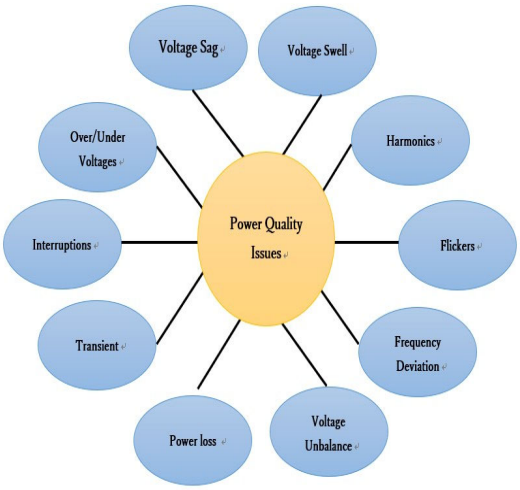
Source: Source: Fast-Charging Infrastructure for Electric and Hybrid Electric Vehicles: Methods for Large-Scale Penetration into Electric Distribution Networks," S. Palanisamy et al.

8. Impact of IRVE Expansion on Distribution Grid

- Research highlights several impacts of IRVE on distribution networks:
  - Power Quality: Integration of IRVEs can lead to power quality issues.
  - Voltage Fluctuation: IRVE charging can cause voltage drops, with some areas experiencing voltages below nominal value, necessitating system upgrades.
  - Power Loss: Increased penetration of EVs leads to higher network power losses, presenting a challenge for future charging needs.



Source: DOI: 10.1201/9781003311829-3.

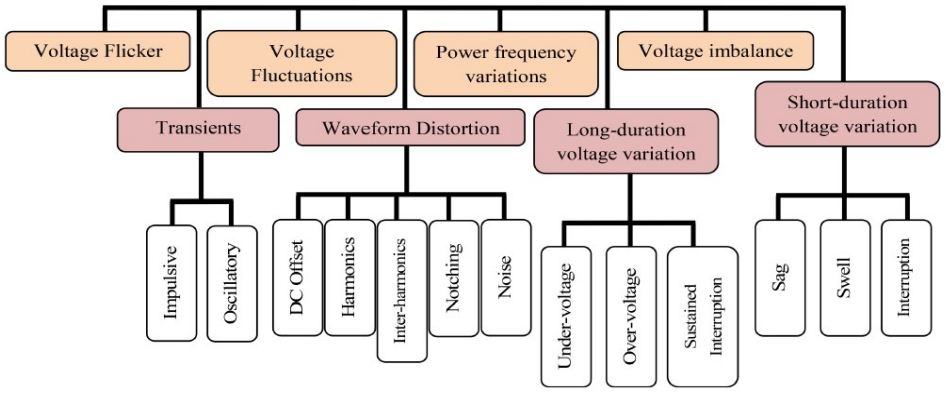


Source: DOI: 10.1186/s44147-023-00193-w, A.

8. Impact of IRVE Expansion on Distribution Grid

PQ issues classification in modern power systems

PQ issue	Characteristics	Causes	Effects
voltage sag	magnitude: (0.1–0.9) V_{rms}frequency: power frequencyduration: 0.5 cycles to 1 min	motor startingsingle line to ground faultsconnection of heavy loads, EVs	protection malfunctionloss of productionmalfunction of some controllers
voltage swell	magnitude: greater than 1.1 V_{rms}frequency: power frequencyduration: 1 cycle to few seconds	capacitor switchinglarge load switchingfaults, EVsbadly regulated transformer	protection malfunctionstress on computers and home appliances
short interruptions	duration: few milliseconds to two seconds	temporary faults	loss of productionmalfunction of fire alarms
long interruptions	duration: greater than two seconds	faultsfailure of protection devices	loss of production
voltage imbalance	difference in three phase amplitude and/or phase angles	single phase loadsingle phasing	heating of induction motors
harmonics	frequency: multiple of power frequency	adjustable speed to driversnonlinear loads, LEDsArc furnaces, EVs, inverter-based DGs	increased lossespoor power factorelectromagnetic interfaces

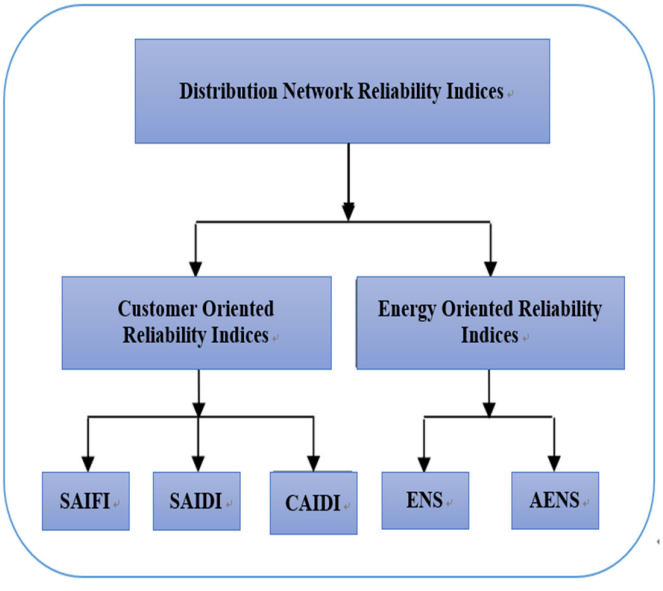


Source: DOI: 10.1049/iet-est.2018.5023

9. PQ Reliability Challenges in Distribution Networks

9. PQ Reliability Challenges in Distribution Networks

- Reliability indices for distribution networks are divided into customer-oriented and energy-oriented categories.
- Customer-oriented indices include
  - SAIFI (System Average Interruption Frequency Index)
  - SAIDI (System Average Interruption Duration Index)
  - CAIDI (Customer Average Interruption Duration Index).
  - Energy-oriented indices
  - ENS (Energy Not Supplied).
  - AENS (Average Energy Not Supplied).



Source: Impact of Electric Vehicle Charging Station Load on Distribution Network," 2018, S. Deb et al.

9. PQ Reliability Challenges in Distribution Networks

- Power quality issues can be categorized as:
  - Generation of Harmonics including; characteristic and non-characteristics harmonics, sub-harmonics, and inter-harmonics
  - Voltage dips and flickers
  - Voltage imbalance
  - Voltage variations (sags and swells)
  - Frequency variations
  - DC components in AC networks
  - power system transients. These events are undesirable in the power-system, and can cause short or long-term problems.

- System reliability indices provide a comprehensive measure of the network's reliability, focusing on both customer and energy metrics but there is a dearth of literature focusing on the impact of the IRVE charging station load on all the aforementioned parameters considered together particularly bus reliability, is underexplored. Distribution Network Operators (DNOs) aim to mitigate the influence of IRVEs on these parameters.
- This analysis is crucial for customer satisfaction and requires statistical data on failure rates, repair rates, outage durations, and the number of consumers at each bus or load point.

9.1 Fast Charging Impact on Distribution Stability

- Fast-charging stations negatively affect power systems by creating numerous power quality (PQ) issues. The power electronics-based components in EV chargers introduce problems such as harmonics, DC injection, and flicker. The extent of current harmonic emission from an EV charger depends on:
  - Power level or rating
  - Charger circuit or topology
  - Grid incoming voltage background harmonic distortion
  - Network impedance between the charger and measurement point
- Additional PQ concerns include:
  - Voltage Sag Resilience: EV chargers must remain operational during voltage sags, sustaining 80% of nominal voltage for up to two seconds.
  - Fault Ride-Through Capability: EV chargers should withstand complete voltage loss during faults for up to 12 seconds.

9.1 Fast Charging Impact on Distribution Stability

- High-frequency switching in fast chargers, operating in the kilohertz range, introduces supra-harmonics. Moreover, the power flow from chargers to EVs is not uniform and varies based on the battery's State of Charge (SoC).
- During a charging cycle, EV chargers operate in two modes:
  - Constant Current (CC) Mode: From zero to 80-85% SoC
  - Constant Voltage (CV) Mode: From 80-85% SoC until fully charged
  - As the battery impedance varies during charging, the current flow also changes. These varying EV charging loads alter system impedance throughout the distribution network, causing shifts in the system resonance point.

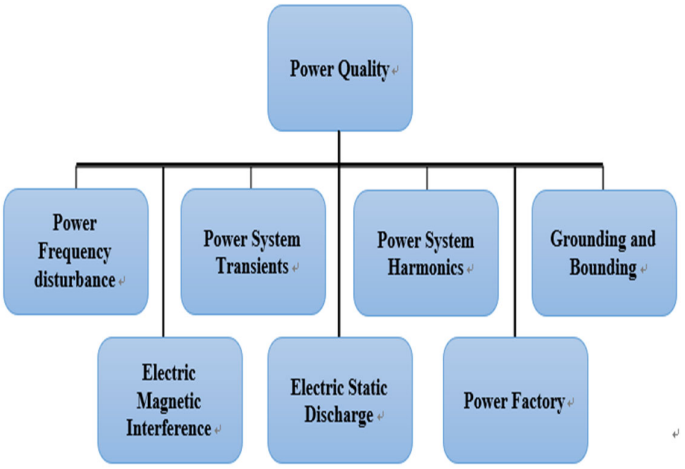
9.1 Fast Charging Impact on Distribution Stability

- Voltage spikes and dips, caused by power frequency disturbances such as system switching activities or outages, affect electrical equipment similarly.
- Transients like ringing, notching, and impulse, which are brief and rapid events, disrupt power systems.
- Harmonics distort waveforms at low frequencies, negatively impacting system components and operations. Interactions between harmonics and system characteristics (resistance, inductance, and capacitance) can have harmful effects.
- Grounding and bonding are crucial for safety, providing a low-impedance path for fault current, and establishing a ground connection plane, this also helps manage electromagnetic interference (EMI) and radio frequency interference (RFI), which affect sensitive electronic circuits and communication devices.

9.1 Fast Charging Impact on Distribution Stability

- Fast-charging stations can exacerbate these power quality issues since the load is not linear, causing detrimental effects on bus voltages, power efficiency, and overall system stability.
- Proper mitigation techniques are necessary to address the impacts of EMI and RFI, ensuring the reliability and efficiency of the distribution grid

- Electrical quality has become a significant concern for users and grid operators, delivering smooth electrical waveforms, particularly with the increased use of sensitive devices in smart grids.
- Deviations in current and voltage waveforms, especially those caused by EVs, present major power quality issues such as harmonics, supra-harmonics, over-currents, voltage distortions, such as sags, swells, unbalances, and fluctuations, with varying durations of impact on users.



Source: DOI: 10.55529/jeet.41.9.18.

9.1 Fast Charging Impact on Distribution Stability

Table. Potential voltage/current distortions due to EVs integrated with the smart grid.

Distortion		Causes	Effects	Duration	Magnitude	Waveform
Current	Current Harmonics	Non-linear characteristics of EVs and EVSEs	Overheating of components	Steady state	0–100th	
	Supraharmonics	Power electronic converters triggered above 2 kHz	Cause to overheat and shorten the useful life of the equipment	Steady state	2–150 kHz	
	Overcurrents	EV load alterations	Malfunction of switching components	>1 min	>>1.1 pu	
Voltage	Sags	Start-up of EV loads	Data loss and damage	0.5 cycle–1 min	0.1–0.9 pu	
	Swells	Switching off EV loads	Hardware damage	0.5 cycle–1 min	1.1–1.4 pu	
	Unbalances	Unbalanced loading	Unequal overheating and (-) sequence currents	Steady state	0.5–2%	
	Fluctuations	Integration level and charging rate of EVs		Intermittent	0.1–7%	

Source: DOI: 10.3390/app14062246.

9.2 Harmonic Emission Guidelines for Fast Chargers

- **IEC 61 000 Series**: While both IEC 61 000 series and IEEE 519 provide frameworks for assessing harmonic current distortion, IEEE 519 is often preferred for its simplicity and alignment with the characteristics of high-power DCFCs.
- **Total Harmonic Distortion (THD)**: Defined as the ratio of the RMS value of harmonic components up to the 50th order to the RMS value of the fundamental component.
- **LV Grid**:
  - **IEC 61 000-3-4**: Sets emission limits for installations with phase current ratings higher than 16 A. However, these limits are based on assumptions suitable for small residential loads and may not be applicable for high-power installations like 350 kW DC fast chargers (DCFC).
  - **IEC 61 000-3-14**: Provides guidelines for developing emission limits to prevent excessive voltage distortion in the LV grid.
- **Medium Voltage (MV) Grids:**
  - **IEC 61 000-3-6:** Offers general guidelines without specific emission limits, suggesting an approach tailored to practical situations.

9.2 Harmonic Emission Guidelines for Fast Chargers

- **IEEE 519**
- **Total Demand Distortion (TDD)**: Defined as the ratio of the RMS value of harmonic components up to the 50th order to the RMS value of the maximum demand current, which includes DC, fundamental, and harmonic components.
- **Emission Limits**:
  - Provides specific harmonic current emission limits for different short-circuit ratio (SCR) values.
  - A lower SCR indicates a higher grid impedance, which makes the grid more sensitive to harmonic emissions. Hence, lower harmonic current emissions are required in weak grid scenarios.
- **Comparison:**
  - **Application**: IEEE 519 is generally simpler to apply compared to IEC 61 000 series because it focuses on TDD and provides specific emission limits based on SCR values.
  - **Flexibility**: IEC 61 000 series offers more flexibility but requires extensive network data and calculations, making it potentially more complex to apply.
  - **Assessment of DCFCs**: IEEE 519 might be more effective for assessing harmonic current emission from DCFCs due to its use of TDD as the assessment metric, which aligns with the characteristics of fast chargers.

9.2 Harmonic Emission Guidelines for Fast Chargers

Table. Comparison of IEEE PQ Standards and IEC 61 000 Series

Within the Scope of the FCS related

Voltage level for MV and LV grid		IEEE PQ standards LV gird: V≤1kV MV grid: 1kV<V≤69kV		IEC 61000 series LV gird: V≤1kV MV grid: 1kV<V≤35kV			
		Level		Compatibility level		Emission (E) and Planning (P) level	
		Value	In standard IEEE	Value	In standard IEC	Value	In standard IEC
Voltage Level	MV grid	Normal operation tolerance: ±10%	1159	Normal operation tolerance: ±10%	61000-2-4	N.A.	
	LV grid	Normal operation tolerance: ±10%	1159	Normal operation tolerance: ±10%	61000-2-4		
Voltage Fluctuation	MV grid	Same as IEC 61000 series	1453	RVC: • ≤ 3% (Normally) • > 3% (Infrequently) Flicker: N.A.	61000-2-12	RVC (Indicative): • 2.5% - 6% (P) Flicker (Indicative): • P_{st} = 0.9 (P) • P_{lt} = 0.7(P) • Guidelines for setting emission level are given	61000-3-7
	LV grid		1453	RVC: • ≤ 3% (Normally) • > 3% (Infrequently) Flicker: • P_{st} = 1 • P_{lt} = 0.8	61000-2-2	RVC: • 3% - 6% (E) Flicker: • P_{st} = $(S_L/S_{TR})^{1/3}$ (E) • P_{lt} = $0.65(S_L/S_{TR})^{1/3}$ (E)	61000-3-5
Voltage unbalance	MV grid	N.A.		$V_n = 2\% \times V_p$ (3% may occur)	61000-2-12	• $V_n = 1.8\% \times V_p$ (P) • Guidelines for setting emission level are given	61000-3-13
	LV grid	$V_n = 2\% \times V_p$	141	$V_n = 2\% \times V_p$ (3% may occur)	61000-2-2	• Planning level can equal to the compatibility level • Guidelines for setting emission level are given	61000-3-14
Harmonic Current	MV grid	TableVI	519	Compatibility level is given only for harmonic voltage		• Planning level is given only for the harmonic voltage • Guidelines for setting emission level are given	61000-3-6
	LV grid	TableVI	519			• Planning level is given only for the harmonic voltage • For $I_{eqp} > 75A$, guidelines are given for setting emission level	61000-3-4 61000-3-14
Harmonic Voltage	MV grid	Fig14	519	Fig14	61000-2-12	• Indicative planning level is shown in Fig14 • Guidelines for setting emission level are given	61000-3-6
	LV grid	Fig14	519	Fig14	61000-2-2	• Planning level can equal to the compatibility level • Guidelines for setting emission level are given	61000-3-14

Note:
• RVC : Rapid Voltage Change • S_L: Apparent power of the load • S_{TR}: Apparent power of the service transformer
• I_{eqp}: Rating phase current of the equipment • V_n: Negative sequence voltage • V_p: Positive sequence voltage

Source: Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures - An Overview," IEEE Open J. Power Electron., 2021, L. Wang et al.

9.2.1 Harmonics Distortions Impact on Distribution Grids

- Waveform distortions represent steady-state deviations from the sinusoidal wave shape, primarily caused by harmonics, inter-harmonics, DC offset, notching, and electrical noise.

➢ Harmonics: These are significant sources of distortion. While mostly sinusoidal, harmonics have frequencies that are integer multiples of the fundamental power frequency (50 or 60 Hz).

➢ They arise due to non-linear loads, communication network interference, faults, control device malfunctions, and resonance frequencies from cable capacitance and power factor correction (PFC) capacitors.

➢ Table shows IEEE Standard 519-1992: Current harmonic limits for general distribution systems (129-69000 V)

IEEE Standard 519-1992 Harmonic Current Limits
Current Distortion Limits for General Distribution Systems (120 Through 69000 V)

Maximum harmonic currents (in percent of I_L)						
Individual harmonic order (odd harmonics)						
I_{sc}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35th	TDD(%)
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20 to <50	7.0	3.5	2.5	1.0	0.5	8.0
50 to <100	10.0	4.5	4.0	1.5	0.7	12.0
100 to <1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

• Even harmonics are limited to 25% of the odd harmonics above.
• Current distortions that result in a DC offset, for example, half wave converters, are not allowed.
• I_{sc}=maximum short-circuit current at PCC and I_L= maximum demand load current (fundamental frequency component) at PCC.

Where
I_{sc} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.
TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).
PCC = Point of common coupling.

IEEE Standard 519-1992 Harmonic Voltage Limits
Voltage Distortion Limits

Bus Voltage at PCC	Individual voltage distortion (%)	Total Voltage distortion (%)
69 kV and below	3.0	5.0
69.001-161 kV	1.5	2.5
161.0001kV and above	1.0	1.5

NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

Source: Impact of Electric Vehicle Charging Infrastructure on the Distribution Network Power Quality: Challenges and Opportunities," G. Sharma et al.,

9.2.1 Harmonics Distortions Impact on Distribution Grids

- Key types include:

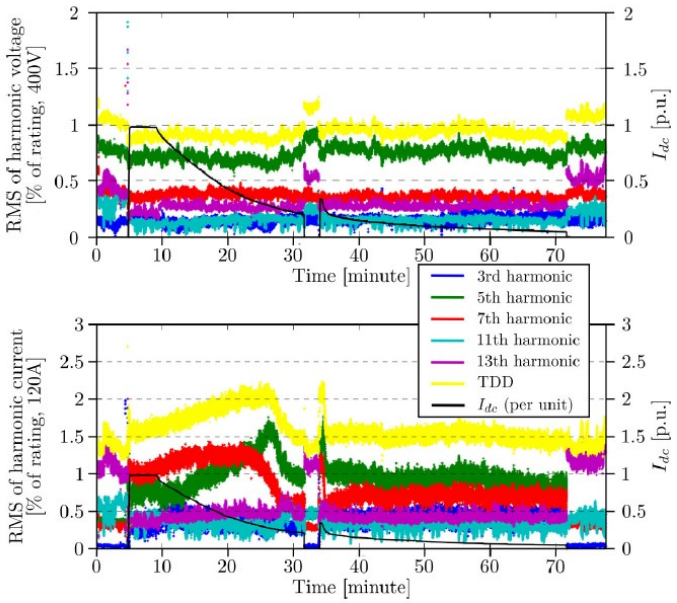
  - Triplen Harmonics: Odd multiples of the 3rd order harmonics (3, 9, 15, etc.), causing significant distortions and excessive neutral currents in grounded-star systems.
  - **Sub-Harmonics:** Frequencies below the fundamental frequency, often generated by resonance in inductive or capacitive systems.
  - **Inter-Harmonics**: Frequencies that are non-integer multiples of the fundamental frequency, arising from current and voltage modulation for control purposes and transient phenomena.
  - **Other notable harmonics:** include characteristic and uncharacteristic harmonics, positive, negative, and zero sequence harmonics, and spatial harmonics.

- EV charging can negatively impact power quality (PQ) in conventional grids by introducing these harmonics.
- It is crucial to adhere to the current and voltage harmonic limits outlined in standards (e.g., IEEE Std. 1100-2005) to ensure the safe and secure operation of fast charging stations (FCS).

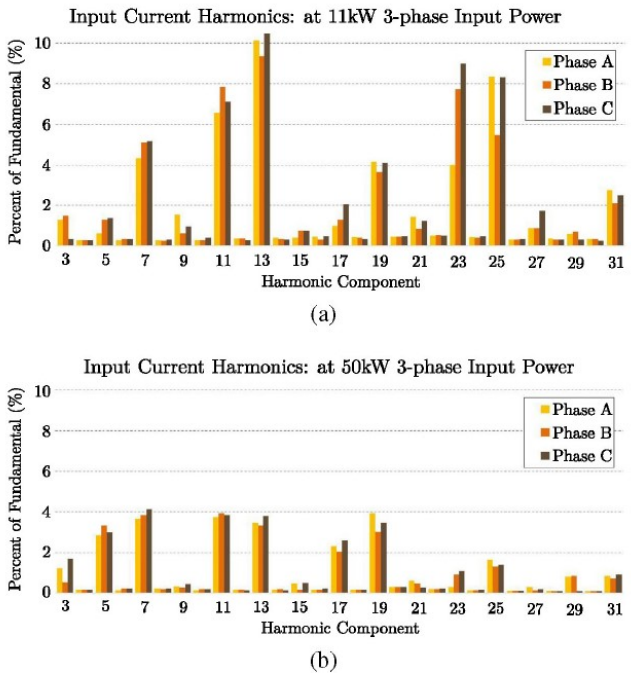
9.2.2 Complexity in Current Harmonic Emission

- The following figures highlight the variability and complexities in measuring and assessing current harmonic emissions from DC fast chargers, emphasizing the utility of TDD for a more accurate representation.
- The harmonic current emission of a 50 kW DCFC was analyzed with input powers of 11 kW and 50 kW.
- **Measurements**:
  - The harmonic current data are presented as a percentage of the fundamental current.
  - Without grid voltage measurement, it is difficult to accurately determine the absolute harmonic current emission because the fundamental current fluctuates throughout the charging cycle.
  - TDD and the percentage of the main individual harmonic current relative to the rated DC output current were recorded.
  - The maximum harmonic current emission does not occur at the peak load.
  - TDD is used as a more effective measure for harmonic current emission compared to THD, as it uses the RMS value of the maximum demand current as the base.

9.2.2 Complexity in Current Harmonic Emission



Main harmonic emission in the charging course of the 50 kW DCFC

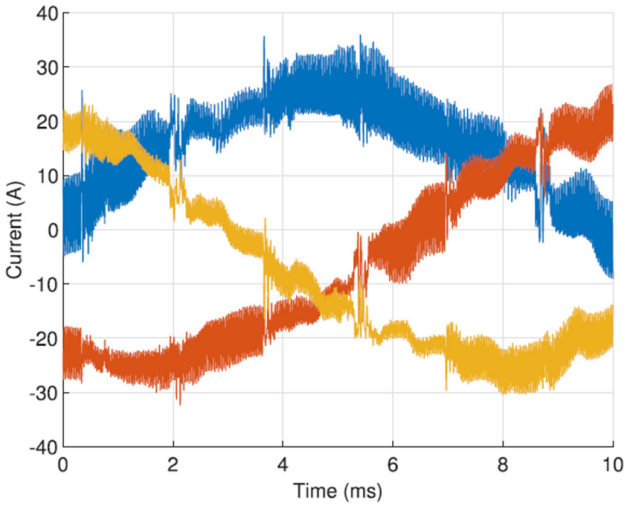


The individual harmonic current of the 50 kW DCFC when: (a) the input power is 11 kW (b) the input power is 50kW .

Source: DOI: 10.1109/OJPEL.2021.3054601.

9.2.3 Supra-harmonics in Impact Modern Power Systems

- **Traditional Harmonics vs. Supra-harmonics**
  - Traditional Harmonics: Analyzed up to 2 kHz with emission limits set for frequencies up to the 50th harmonic.
  - Supra-harmonics: Frequencies between 2 kHz and 150 kHz, increasingly relevant due to power electronic systems.
- **Emergence and Impact**
  - Sources: Power converters, including electric vehicle onboard chargers (OBCs) and DC fast chargers (DCFCs), often operate in the supra-harmonic range.
  - Effects on LV Grid: Supra-harmonics can cause significant voltage distortion, equipment heating, audible noise, and disruptions in power-line communication (PLC).



Supra-harmonics in the 3-phase currents measured at the input of a DCFC

Source: DOI: 10.1109/OJPEL.2021.3054601.

9.2.3 Supra-harmonics in Impact Modern Power Systems

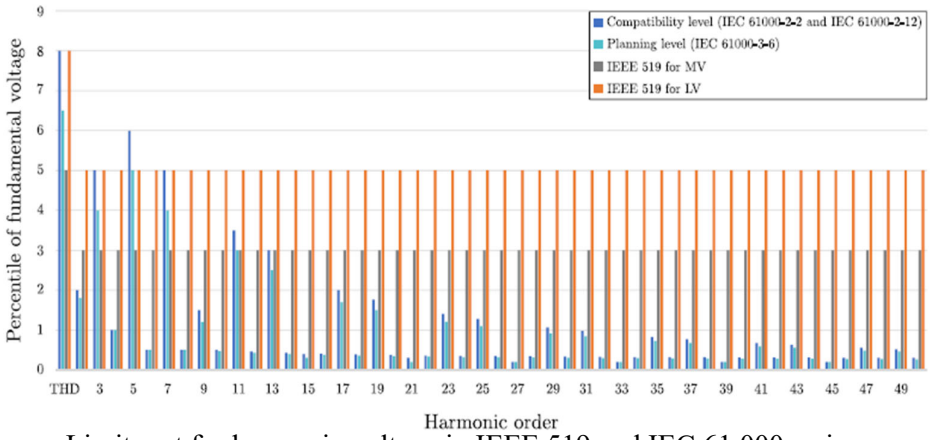
- **Emergence and Impact**
  - Sources: Power converters, including electric vehicle onboard chargers (OBCs) and DC fast chargers (DCFCs), often operate in the supra-harmonic range.
  - Effects on LV Grid: Supra-harmonics can cause significant voltage distortion, equipment heating, audible noise, and disruptions in power-line communication (PLC).
- **Standards IEC 61 000-4-30**
  - Current Standards: IEC 61 000-4-30 includes guidelines on supra-harmonics, but no specific standards for DCFCs.
  - Ongoing Research: The impact of supra-harmonics from DCFCs is under investigation, and further research is needed to establish standards and assess grid interactions.

9.2.4 Harmonic Voltage Distortion in Power Grids

- Harmonic voltage distortion standards are well-defined with guidelines and limits for both LV and HV grids, while voltage unbalance standards are more specific to LV grids and offer general guidance for MV grids without specific IEEE standards.
- **Low Voltage (LV) Grid**:
  - **IEC 61 000-2-2**: Sets the compatibility level for harmonic voltage distortion.
  - **IEC 61 000-3-14**: Offers guidelines for setting harmonic voltage emission levels. Emission levels can be converted between current and voltage using known grid impedance at the point of common coupling (PCC).
- **Medium Voltage (MV) Grid:**
  - **IEC 61 000-2-12**: Provides compatibility levels for harmonic voltage distortion.
  - **IEC 61 000-3-6**: Introduces indicative planning levels for harmonic voltage emission. Specific emission values are not provided; instead, guidelines are given.
- **IEEE 519:**
  - Specifies the maximum Total Harmonic Distortion (THD) for grid voltage in both LV and MV grids, providing a clear standard for acceptable levels of harmonic distortion.

9.2.4 Harmonic Voltage Distortion in Power Grids

- **Low Voltage (LV) Grid**:
  - **IEEE 141** and **IEC 61 000-3-14**: State that the negative sequence voltage should be less than 2% of the positive sequence voltage.
  - **IEC 61 000-3-14**: Provides guidelines for deriving emission levels for large installations, such as high-power DC fast chargers (DCFC).
- **Medium Voltage (MV) Grid**:
  - **IEC 61 000-3-13**: Provides indicative planning levels for voltage unbalance.
  - No specific IEEE standards exist for voltage unbalance in the MV grid.



Limits set for harmonic voltage in IEEE 519 and IEC 61 000 series.

Source: Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues, and Mitigation Measures - An Overview, Wang et al., IEEE Open Journal of Power Electronics, 2021.

9.2.5 IRVE Voltage Imbalance Impact on Grids PQ

- It has been mentioned in many studies that if a Fast Charging IRVE System is supplied only by an electric-grid without using any electrical storage system or renewable energy sources, then there is direct impact of charging/discharging of EV on the power quality of grid.

- Short-Duration Variations
  - These kinds of problems may be instantaneous, momentary and/or temporary in the form of interruption, sag and swell.
  - The cause of these kind of problems may be a fault in the system, large load energization and loose connections. As per IEEE-1250,
    - Instantaneous interruption - between 0.5 and 30 cycles
    - Momentary interruption - between 30 cycles and 2 seconds
    - Temporary interruption – between 2 seconds and 2 minutes.
  - Similarly, sags and swells are the short duration undesired events. Sag is the temporary reduction in the RMS voltage between 0.1 and 0.9 pu, and swell is the increase in voltage magnitude between 1.1 and 1.8 which can last between 0.5 cycles and 1 pu.

9.2.5 IRVE Voltage Imbalance Impact on Grids PQ

■ Long-Duration Variations

- These problems can persist for longer than 1 minute as per IEEE-1159 and ANSI-C84.1 standard. The reason for these variations are switching operations and load variations. These disturbances are categorized as sustained interruptions, causing over-voltages, and under-voltages.
- Sustained interruptions: As per IEEE standards, duration is more than 1 minute. These are the most serious kind of power quality problems often caused by fault incidences, incorrect relay operation, and scheduled maintenance.
- Over-voltages: Increase in RMS voltage from 1.1 to 1.2 pu for more than 1 minute. These over-voltages can be further classified as a lightning overvoltage, switching overvoltage, and over-voltages caused by insulation failure, ferro-resonance, tap changer transformer etc.
- Under-voltages - duration is more than 1 minute, and increase in rms voltage from 1.1 to 1.2 pu

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9.2.5 IRVE Voltage Imbalance Impact on Grids PQ

■ Other major power quality problems

- EVs are a new and dynamic load which may cause power quality-related problems having detrimental impacts on the electric grid. These effects include harmonic distortion, voltage unbalance, voltage drop, equipment overloading, phase unbalance and problems related to power system stability etc.
- When many EV chargers are linked, the voltage at the supply end likewise decreases. This issue arises as a result of overloading caused by a high number of EVs. Figure shows the voltage pattern variation both before and after the EV charger connection.
- When comparing the voltage with and without the connection of EV chargers, as shown in Fig., it is clear that harmonic disruption has an impact on the voltage.

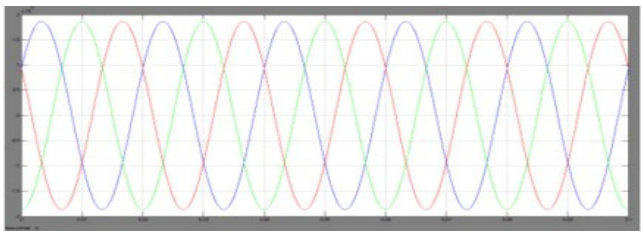


Fig. Input Voltage, before connecting Charger.

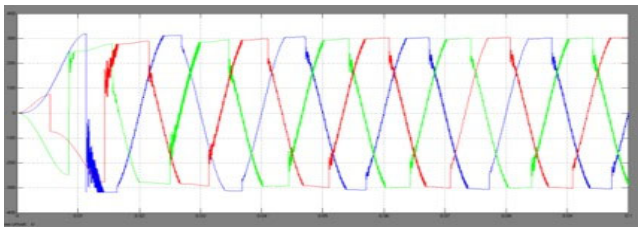


Fig. Input Voltage, after connecting Charger.

Source: DOI: 10.55529/jeet.41.9.18.

10. Planning Framework for IRVE in Power Distribution

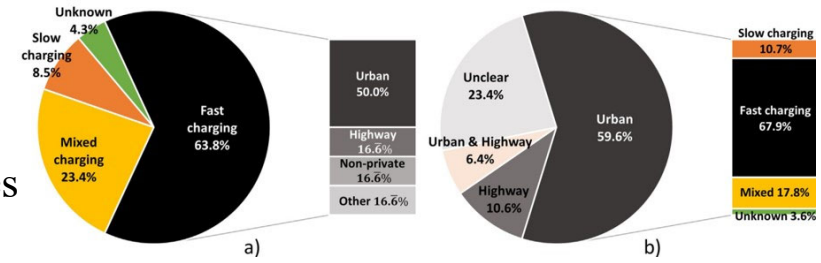
10. Planning Framework for IRVE in Power Distribution

- The demand for electric vehicle (EV) charging infrastructure (IRVE) is crucial for planning and managing a reliable and efficient power distribution network. By modeling IRVE demand, we can predict where and when EVs will need to charge, thus allowing for better infrastructure planning and mitigating potential power quality problems on the grid.
- Without proper demand modeling, unexpected high loads can lead to reduced power quality.
- Modeling IRVE demand is essential for efficient infrastructure planning and mitigating power quality problems on the distribution grid.
- linking IRVE demand modeling with power quality management, can create a resilient and efficient power distribution network that meets the needs of EV users while maintaining high standards of power quality.
- This approach focuses on modeling IRVE charging demand. this subject examines how demand for charging stations is modeled through various location methods and capacity constraints.
- This approach focuses on understanding and predicting the demand for electric vehicle (EV) charging infrastructure (IRVE) and the capacity Constraints

10. Planning Framework for IRVE in Power Distribution

- This approach focuses on understanding and predicting the demand for electric vehicle (EV) charging infrastructure (IRVE) and the capacity Constraints
- Fig. provides a detailed breakdown of studies by charging technology and target area, highlighting urban area studies and the planning of IRVE for different vehicle types and locations and Table compares node-based, flow-based, and agent-based location methods.

Comparison of the reviewed location methods			
Criteria	Method		
	Node-based	Flow-based	Agent-base
Data required	Very Low	Low	Very High
Use Behaviour modelling	-	○	+
Representation of demand	-	○	+
Most suitable target area	Urban	Highway	Both
Most suitable charging type	Slow & Fast	Fast	Slow & Fast



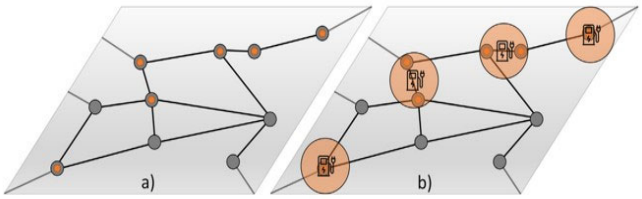
Source: Electric Vehicle Charging Infrastructure Planning for Integrated Transportation and Power Distribution Networks: A Review," T. Unterluggauer et al

10. Planning Framework for IRVE in Power Distribution

- In summary, the modeling approach for IRVE demand integrates various methods to realistically capture user demand for charging infrastructure. It considers spatial and temporal variations while balancing data requirements with the level of detail in the insights provided. This comprehensive approach ensures an accurate and practical understanding of IRVE demand.
- **Trade-offs and Variability**: Charging demand involves trade-offs between waiting time and costs, which vary by location and time.
- **Location Methods:**
  - **Node-based:** Most favourable due to lower data requirements.
  - **Flow-based:** Requires more data but provides detailed insights.
  - **Agent-based:** Captures individual behaviours but is data-intensive.
- **Capacity Constraints:**
  - Modelled using queuing models or flow-capacity formulations, similar to transportation models.

10. Planning Framework for IRVE in Power Distribution

- **Simplified Illustrations for:** Charging infrastructure planning framework for integrated transportation and power distribution networks.
- **Node-based:** Charging infrastructure is placed to cover specific demand nodes in a transportation network.
- **Flow-based:** Charging infrastructure is located to cover the maximum traffic flows in a network.
- **Agent-based:** Charging infrastructure is optimized based on individual vehicle tours and charging opportunities.



Simplified illustration of the Node-based approach



Simplified illustration of Flow-based approach

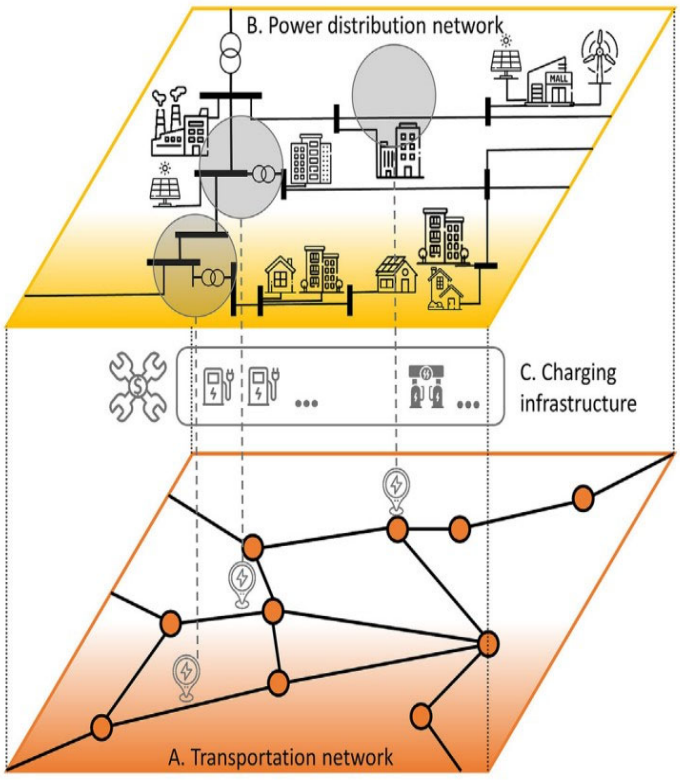


Simplified illustration of Agent-based approach

Source: Electric Vehicle Charging Infrastructure Planning for Integrated Transportation and Power Distribution Networks: A Review," T. Unterluggauer et al

10. Planning Framework for IRVE in Power Distribution

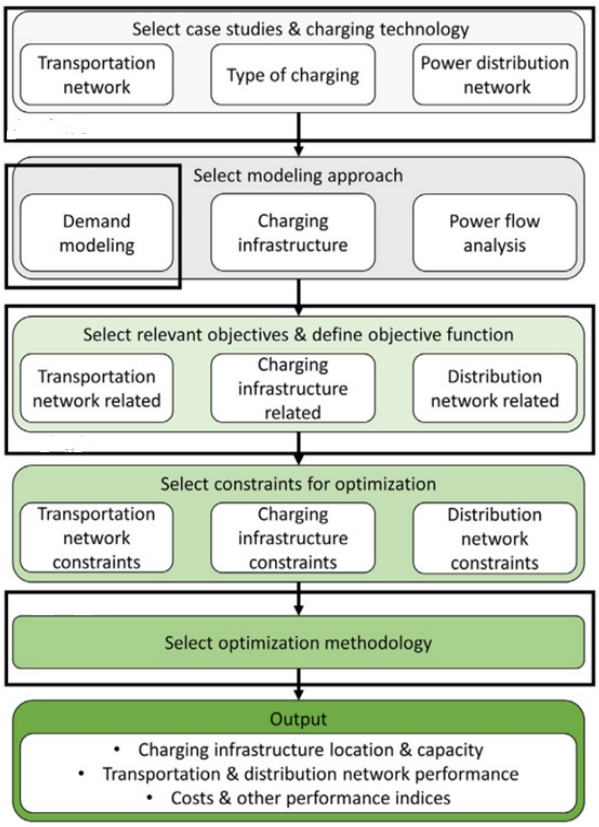
- The problem of planning electric vehicle (EV) charging infrastructure within integrated transportation and distribution networks involves finding optimal locations and capacities for charging stations while considering both the transportation network (TN) and distribution network (DN).
- This complex issue arises because decisions about charging station placement and capacity can benefit one network while potentially harming the other. For example, charging infrastructure impacts supply quality, travel behaviour, and convenience in the TN, and also affects DN costs and performance.



Source: Electric Vehicle Charging Infrastructure Planning for Integrated Transportation and Power Distribution Networks: A Review," T. Unterluggauer et al

10. Planning Framework for IRVE in Power Distribution

- A simplified planning framework involves six key steps, each considering three perspectives: the TN, DN, and charging infrastructure. The process starts with defining the application focus, including the type of charging technology (slow or fast), target area (urban, suburban, rural), and study scope.



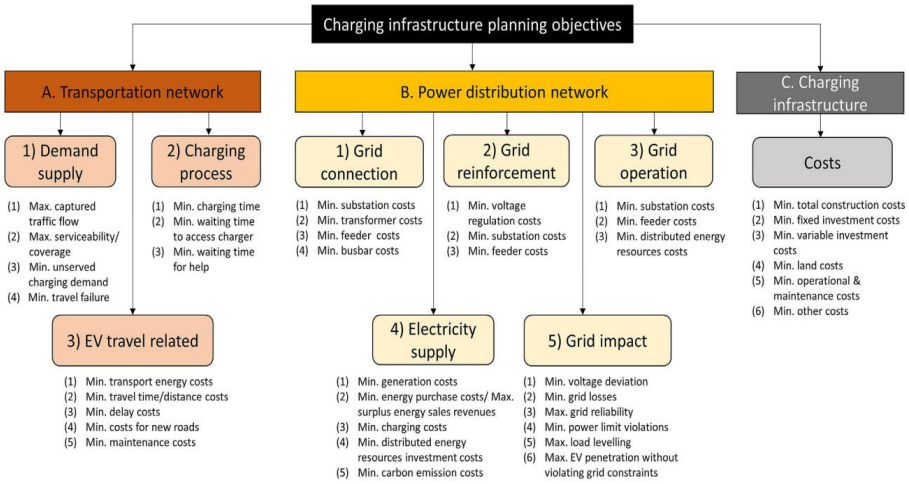
Source: Electric Vehicle Charging Infrastructure Planning for Integrated Transportation and Power Distribution Networks: A Review," T. Unterluggauer et al

10. Planning Framework for IRVE in Power Distribution

- **Type of Charging Infrastructure**: Different technologies (DC fast chargers vs. AC slow chargers) influence costs and grid stress. A mix of technologies might be more optimal than using only one type.
- **Target Area**: The deployment area (e.g., urban vs. rural) affects both network structures and user behavior.
- **Modeling Approaches**: Selecting methods for demand modeling in the TN and power flow analysis in the DN impacts the scalability and detail of the study.
- **Planning Objectives and Constraints**: Objectives can be transportation network-related, distribution network-related, or charging infrastructure-related, with constraints ensuring feasible solutions. Constraints include power balance, voltage limits, budget limits, and travel time limits.
- **Optimization Algorithms**: Various methods, including conventional, nature-inspired, and hybrid approaches, are used to determine optimal locations and capacities for charging infrastructure.

10. Planning Framework for IRVE in Power Distribution

- **The objectives for planning can be classified into three categories:**
  - Transportation Network (TN) Objectives: Related to service quality and user convenience.
  - Distribution Network (DN) Objectives: Related to grid connection, reinforcement, operation costs, and impact on electricity supply.
  - Charging Infrastructure IRVE Objectives: Related to minimizing overall costs and improving efficiency.



Source: Electric Vehicle Charging Infrastructure Planning for Integrated Transportation and Power Distribution Networks: A Review," T. Unterluggauer et al

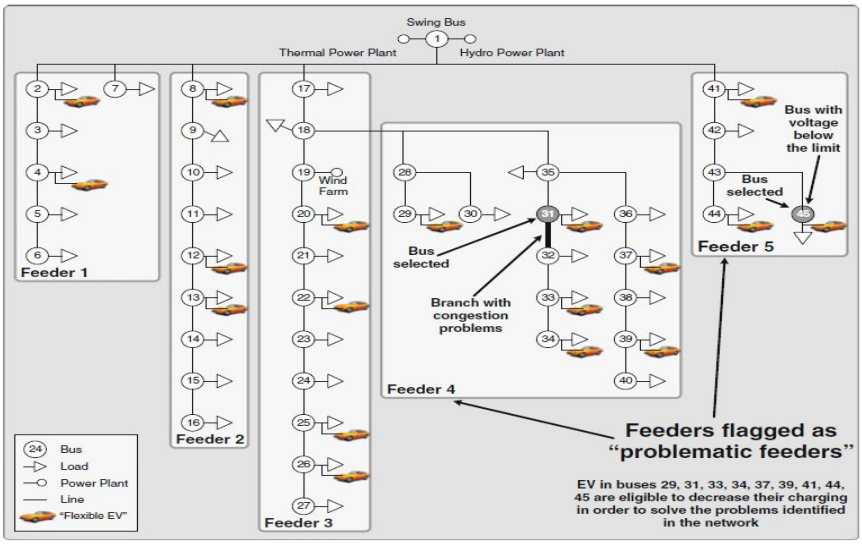
10.1 Heuristic Methodology for Planning IRVE Impact

- **Heuristic Methodology:** To better understand the impact of IRVE on distribution networks, various Dynamic Studies have been explored to manage the effect of EV deployment on distribution grids.
- **Methodology Overview:**
  - **Methodology 1:** Utilizes a deterministic approach to distribute EVs across network buses and assess their daily load impacts. It considers three charging strategies: dumb charging, multiple tariff, and smart charging.
  - **Methodology 2:** Utilizes a Markov chain to simulate EV movement over the course of a week, combined with a Monte Carlo simulation to explore various scenarios, including management strategies:
    - Minimize energy purchase deviations.
    - Reduce renewable energy waste.
    - Flatten load profiles.
    - Address technical issues such as voltage deviations and branch overloading.

10.1 Heuristic Methodology for Planning IRVE Impact

■ Key Aspects of Methodology 2:

- Charging Rates: Covers EV charging rates from 3 kW (level 1) to 40 kW (level 3).
- Time Horizon: Extends the evaluation period to one week with half-hour intervals, allowing for detailed analysis of load variations and network conditions.
- Adaptability: The approach can be adjusted for different time periods, such as one year, to assess seasonal load changes.



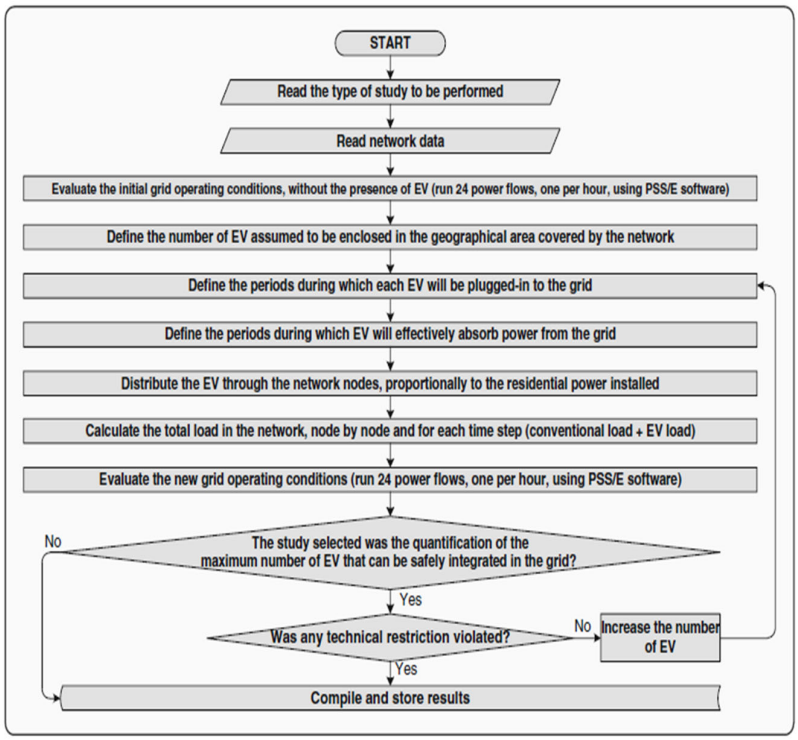
Method used to select the EV whose charging will be decreased.

Source: Electric Vehicle Integration into Modern Power Networks: Advanced Models and Simulation Tools to Address Electric Vehicle Power System Integration (Steady-State and Dynamic Behavior)," F.J. Soares et al.

10.1 Heuristic Methodology for Planning IRVE Impact

■ Algorithm for Integration Analysis:

- Define the study objective (impact assessment or maximum integration).
- Evaluate initial network conditions without EVs.
- Determine the number of EVs in the network.
- Specify connection periods for each EV.
- Define power draw periods based on the charging strategy.
- Distribute EVs across network nodes.
- Calculate total network load and evaluate new operating conditions.
- Adjust EV numbers and repeat if necessary.
- Store all relevant data.



Flowchart of the algorithm based in Methodology 1

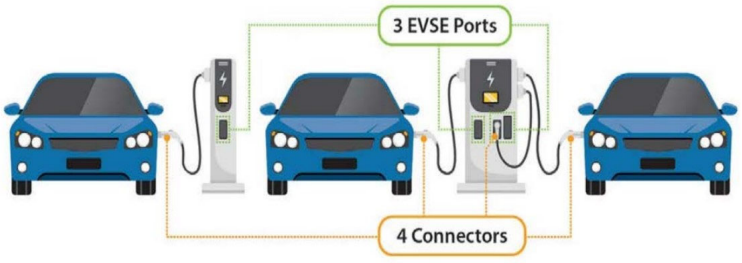
Source: Electric Vehicle Integration into Modern Power Networks: Advanced Models and Simulation Tools to Address Electric Vehicle Power System Integration (Steady-State and Dynamic Behavior)," F.J. Soares et al.

10.1 Heuristic Methodology for Planning IRVE Impact

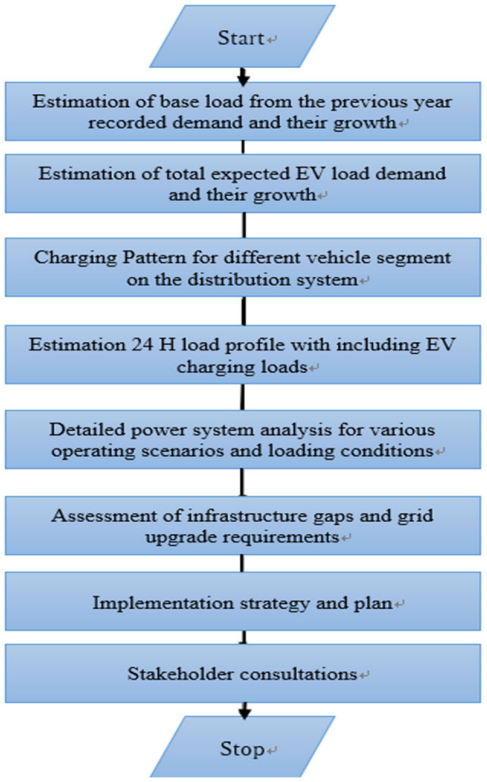
- **Heuristic Approach for Real-Time Issues:** This heuristic approach, while not optimal, provides a practical method for addressing LV and line overloading issues quickly.
- **First Stage:**
  - Gather network data and run power flow analysis.
  - Flag problematic buses based on voltage and branch ratings.
  - Calculate required load reductions iteratively for problematic buses.
- **Second Stage:**
  - Identify "flexible EVs" to reduce charging rates.
  - Initially, reduce charging rates of flexible EVs while considering SOC requirements. If needed, reduce charging rates of all EVs in problematic areas to ensure system security.

10.2 Analysis of Distribution System Planning for IRVE

- The rise in electric vehicle (EV) charging will increase power and energy demands on the distribution system, potentially causing overloading, inefficient reactive power compensation, and poor voltage profiles. Current infrastructure is not equipped for this higher demand, necessitating upgrades and new equipment. Proper planning and modification of the distribution system are required to accommodate EV loads effectively. DISCOs must enhance the infrastructure to support all EV charging needs.



Source: The 2030 National Charging Network: Estimating U.S. Light-Duty Demand for Electric Vehicle Charging Infrastructure," E. Wood et al., Alternative Fuels Data Centre, 2023.



Typical distribution infrastructure planning for Accommodating EV charging load

Source: Fast-Charging Infrastructure for Electric and Hybrid Electric Vehicles: Methods for Large-Scale Penetration into Electric Distribution Networks," S. Palanisamy et al.

10.2 Analysis of Distribution System Planning for IRVE

- Before conducting a detailed power system analysis, it's crucial to assess the current distribution system's capability and identify additional requirements with IRVE charging loads included.

➢ **Estimate EV Demand:** Determine the expected number and types of EVs that will use the distribution system by analyzing historical vehicle registrations, growth trends, and EV penetration. Map this data to estimate regional EV concentrations and public charging station needs.

Data Area	Variables
Population	Population by statistical areas and future projections
Housing	Number in dwellings in houses apartments
Metropolitan area definitions	Definition of metropolitan areas
Passenger vehicle stock	Passenger vehicle stock
Electric vehicle registrations	Registration of new electric vehicle, including EV
Existing charging infrastructure	Counts of IRVE
Charging Infrastructure to electric vehicle relationship	Ratio of electric vehicle to charging points, based on market size and or electric share
Charging behaviour	Observed charging rates of charging for residential, workplace, public, and DC fast chargers
Travel behaviour	Annual mileage, commute distance, vehicle information

Source:Regional Charging Infrastructure Requirements in Germany Through 2030," M. Nicholas et al., ICCT, 2020

➢ Geospatial Analysis: Use geospatial analysis to identify regions with high EV concentrations based on factors such as population and industry locations. This analysis will help estimate the number of charging stations needed and align this with DISCOs infrastructure for planning purposes.

➢ Power System Analysis: Perform a detailed power system analysis, including load flow, short-circuit, and harmonic analyses, for scenarios both with and without EVs. This should account for expected growth over the next 5–10 years

10.2 Analysis of Distribution System Planning for IRVE

- A detailed power quality and load flow analysis assesses the current distribution system infrastructure and determines the necessity for additional modifications to equipment and feeders to meet future IRVE charging loads as follows:

➢ Voltage profiles across various buses in the distribution system.

➢ Voltage drops throughout the distribution system.

➢ Loadings of equipment and circuits in the distribution system.

➢ Ratings, impedance, and tap settings of distribution transformers.

➢ Real and reactive power flow in different branches of the distribution system.

➢ Real and reactive power losses within the distribution system.

➢ Ratings, locations, and types of reactive power compensation devices (fixed or adjustable).

➢ System performance under minimum, maximum, and normal loading conditions.

- Expected Outcomes:

➢ Load Flow Analysis: Insights into voltage profiles, loadings, and power flows.

➢ Short-Circuit Analysis: Evaluation of system response to fault conditions.

➢ Harmonic Analysis: Assessment of harmonic distortion and its impact on the system

Presentation Material 2- 3

Activity 2-2-2 Simulation of the EV Penetration on Distribution Network (DIgSILENT PowerFactory)

Simulation of the EV Penetration on Distribution Network (DIgSILENT PowerFactory)

Activity 2-2-2

JICA Expert Team

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-1-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**			
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

Contents

1. Introduction
2. Coincidence Definition
3. Simulation in DIgSILENT PowerFactory
   3.1 Coincidence Factor of Electric Vehicle Charging Points
   3.2 Coupling Effect
   3.3 Scaling Factor and Active Units
   3.4 Analysis of Voltage Profile along Feeder in Distribution Network

1. Introduction

Introduction

Background and Context

- Aligning with national goals for sustainable energy development, it is also important to integrate EVs, which do not emit CO2 when driven, into the electricity system to achieve a stable, low-carbon electricity supply in Tunisia.
- However, as electric vehicles (EVs) become increasingly popular, the demand for EV recharging can place a significant load on the power distribution grid, affecting the stability and efficiency of the electricity system.

Scope of the Study

- This study focuses on evaluating the impact of EV penetration on a distribution network, using specific metrics and methodologies. Key areas of analysis include:
  - Coincidence factor to evaluate peak demand due to simultaneous EV charging,
  - Coupling effects that account for the mutual influence of multiple load types,
  - Voltage profile analysis to assess power quality along distribution feeders.

2. Coincidence Definition

Coincidence Definition

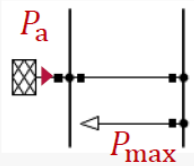
- The diversity of electric load demand is a key factor in determining the system's peak demand.
- According to the IEC(International Electrotechnical Commission), the Coincidence Factor(CF) is defined by the ratio, expressed as a numerical value or as a percentage, of the simultaneous maximum demand of a group of electrical appliances or consumers within a specified period, to the sum of their individual maximum demands within the same period.
- The coincidence factor determines the possibility of all loads running concurrently.
- Coincidence curves $g(n)$ take a stochastic approach for the power consumption of multiple consumers into account.
- They depend on the number of customers n of a specific load type that have an impact on the investigated branch or node.

Source: A stochastic approach to determine the energy consumption and synthetic load profiles of different customer types

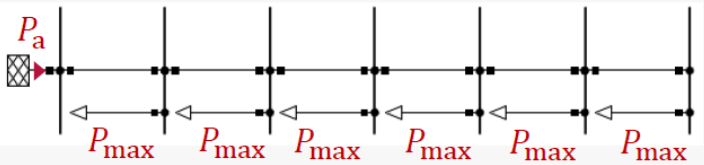
Coincidence Definition

- Planning of a public network requires assumption for loads.
- Without detail information, a conservation estimation is needed.
- As the actual load is stochastic, a coincidence effect can be taken into account.

Power assumption for planning purposes P_a



$P_a \approx P_{max}$

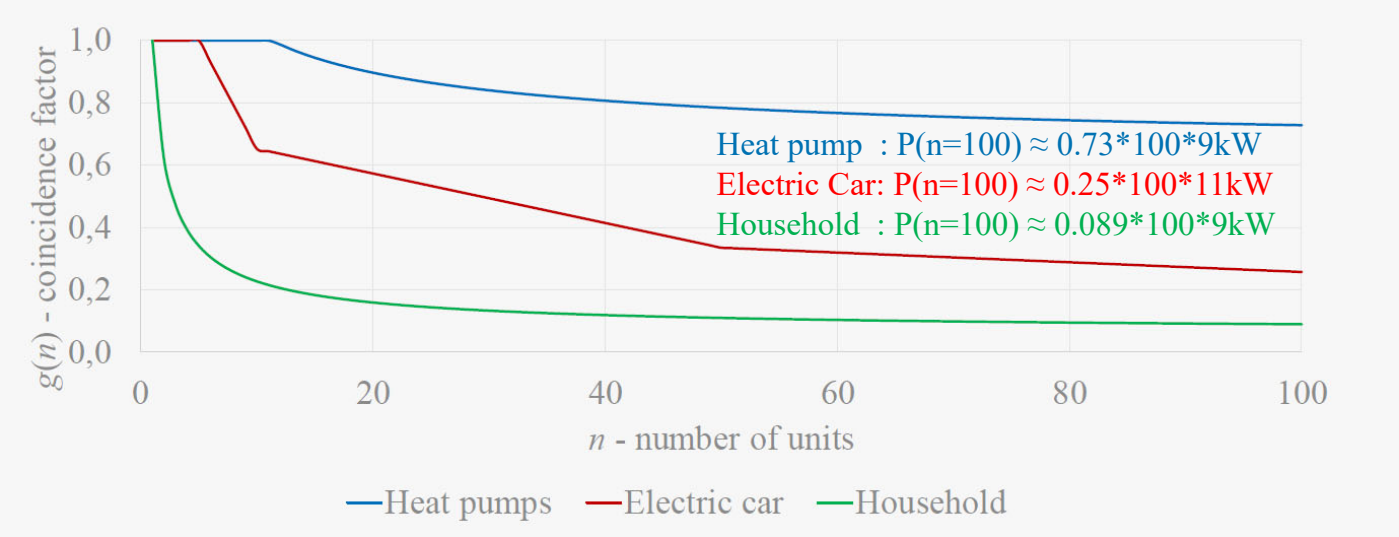


$P_a < \sum P_{max}$ ← coincidence effect due to stochastic load

Source: Web seminar on the new Low-Voltage Load Flow Calculation of *PowerFactory*

Coincidence Definition

■ Sample of Coincidence Factor Curve



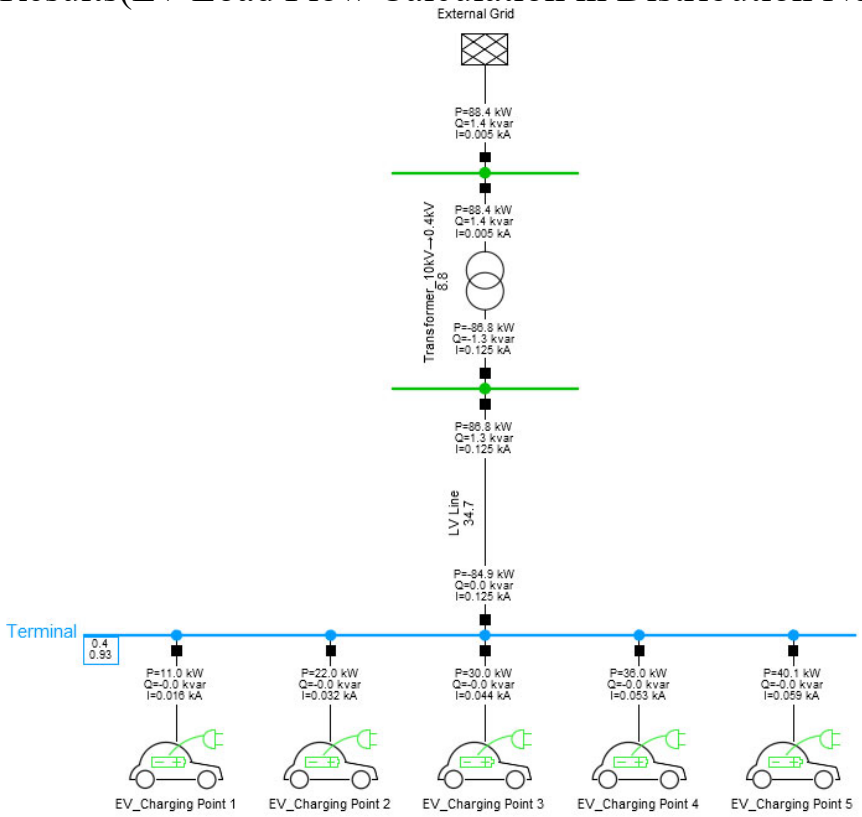
- For forming the Coincidence factor, the inputs such as available charging power, EV battery size, number of EVs, driving patterns, plug-in curves etc. need to be considered.
- In this presentation, the coincidence curves in DIgSILENT Software's Library will be applied.
- These curves are based on the data of German distribution operators.

Source: Demand Factor Identification of Electrical Vehicle Charging Points For Distribution System Planning

3. Simulation in DIgSILENT PowerFactory

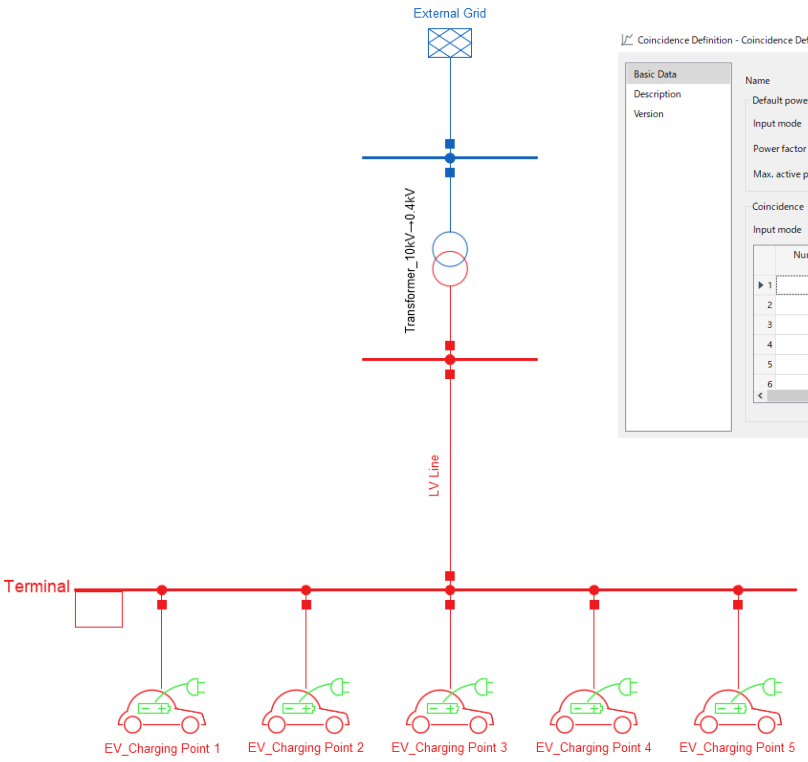
3.1 Coincidence Factor of EV Charging Points

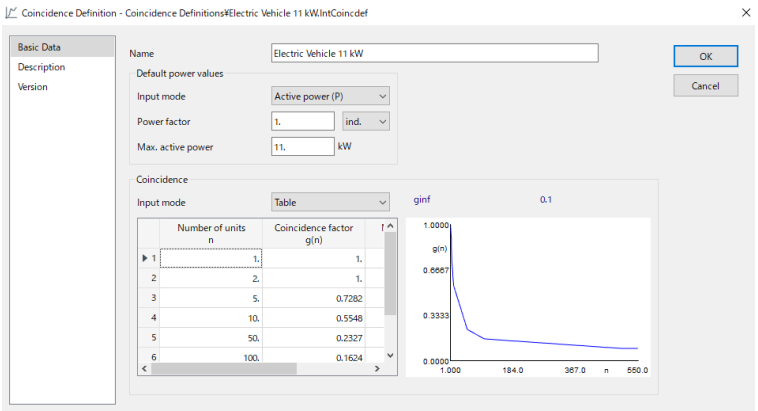
- Calculation Results(LV Load Flow Calculation in Distribution Network Analysis)



3.1 Coincidence Factor of EV Charging Points

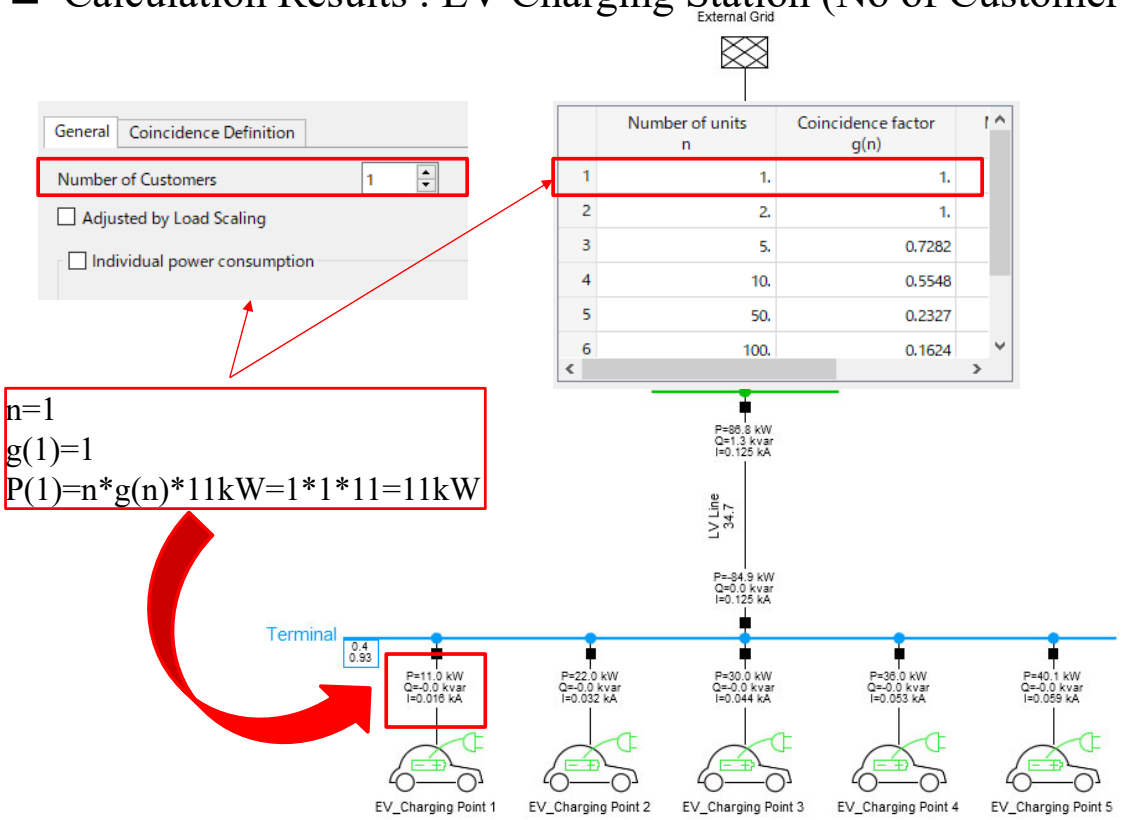
- Low voltage load flow will be analyzed with EV Coincidence Factor Curve





3.1 Coincidence Factor of EV Charging Points

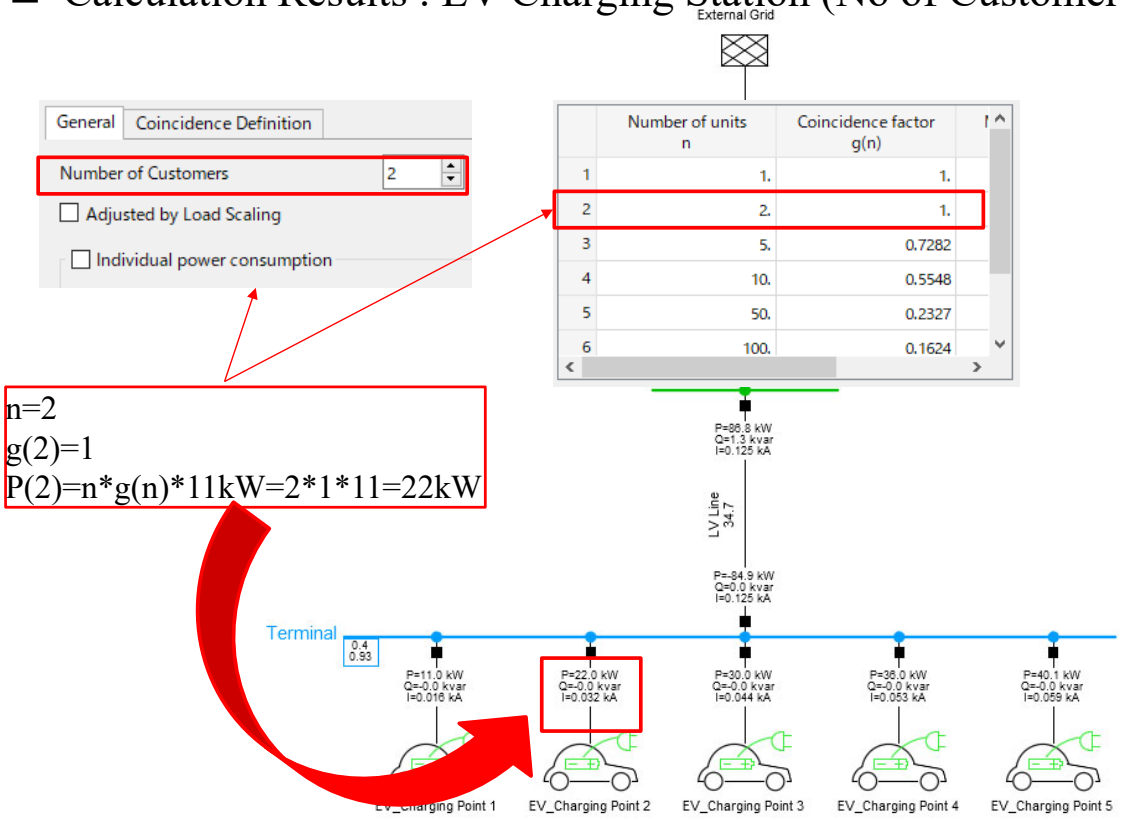
■ Calculation Results : EV Charging Station (No of Customer = 1)



n=1
g(1)=1
P(1)=n*g(n)*11kW=1*1*11=11kW

3.1 Coincidence Factor of EV Charging Points

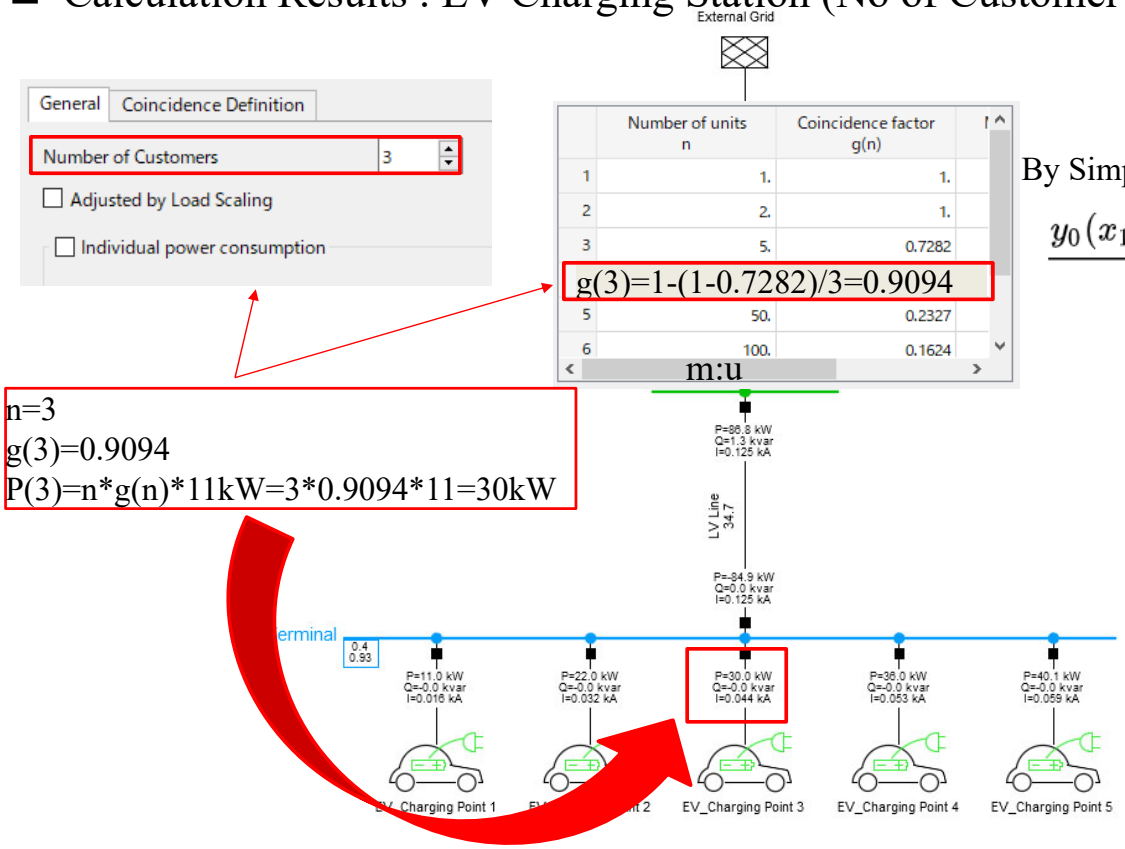
■ Calculation Results : EV Charging Station (No of Customer = 2)



n=2
g(2)=1
P(2)=n*g(n)*11kW=2*1*11=22kW

3.1 Coincidence Factor of EV Charging Points

■ Calculation Results : EV Charging Station (No of Customer = 3)



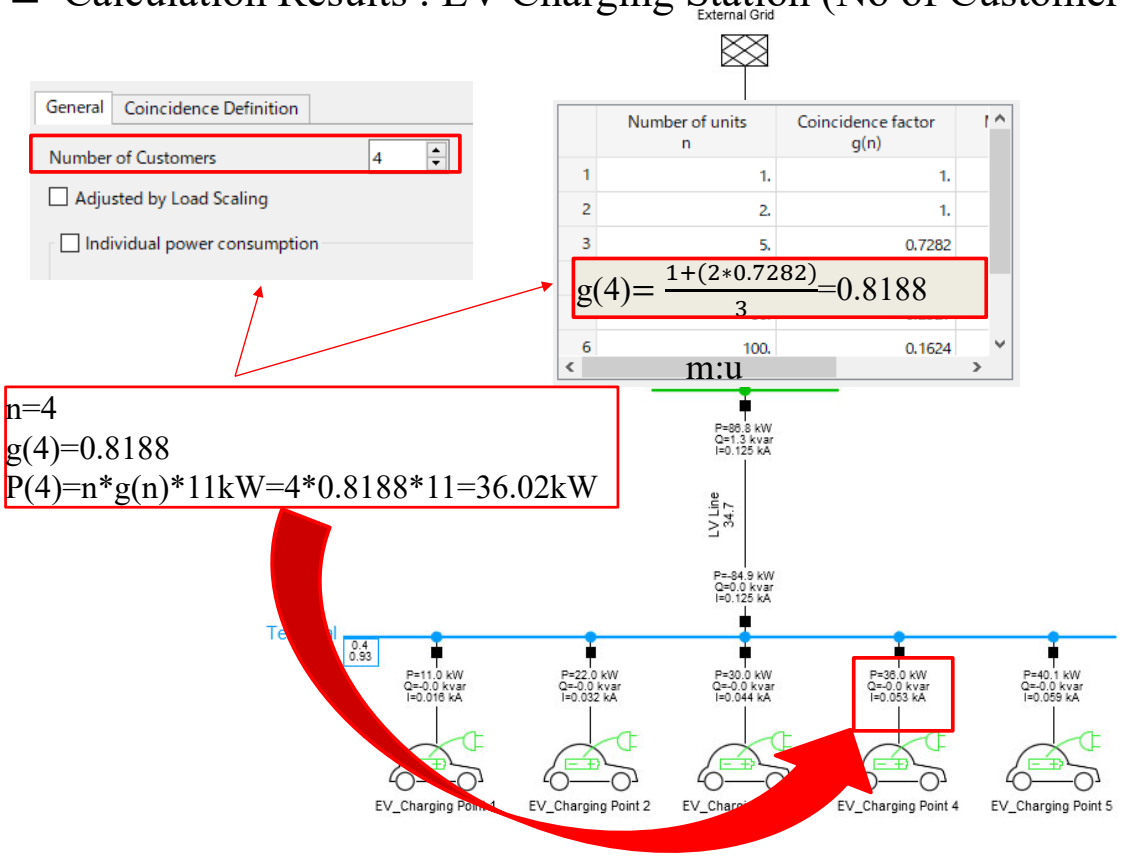
n=3
g(3)=0.9094
P(3)=n*g(n)*11kW=3*0.9094*11=30kW

By Simple Linear Interpolation Eq

$$\frac{y_0(x_1 - x) + y_1(x - x_0)}{x_1 - x_0}$$

3.1 Coincidence Factor of EV Charging Points

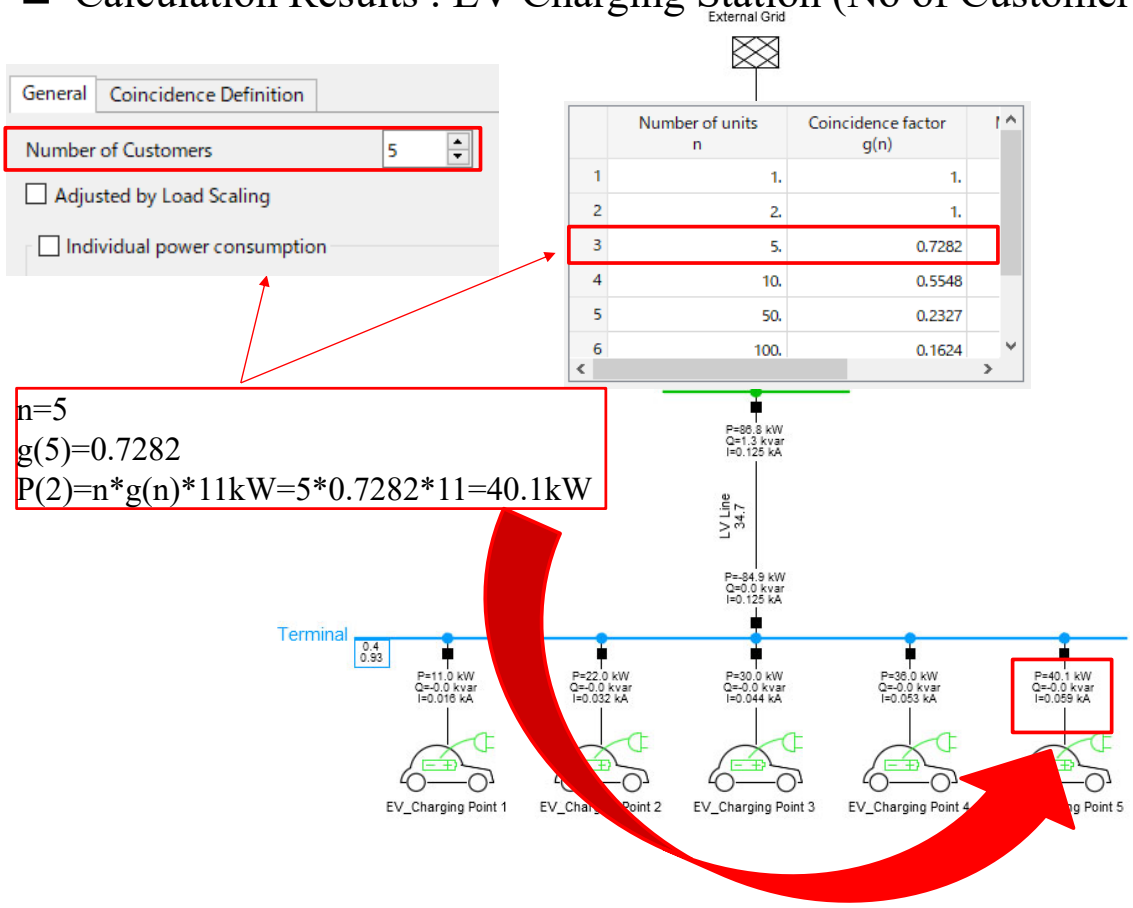
■ Calculation Results : EV Charging Station (No of Customer = 4)



n=4
g(4)=0.8188
P(4)=n*g(n)*11kW=4*0.8188*11=36.02kW

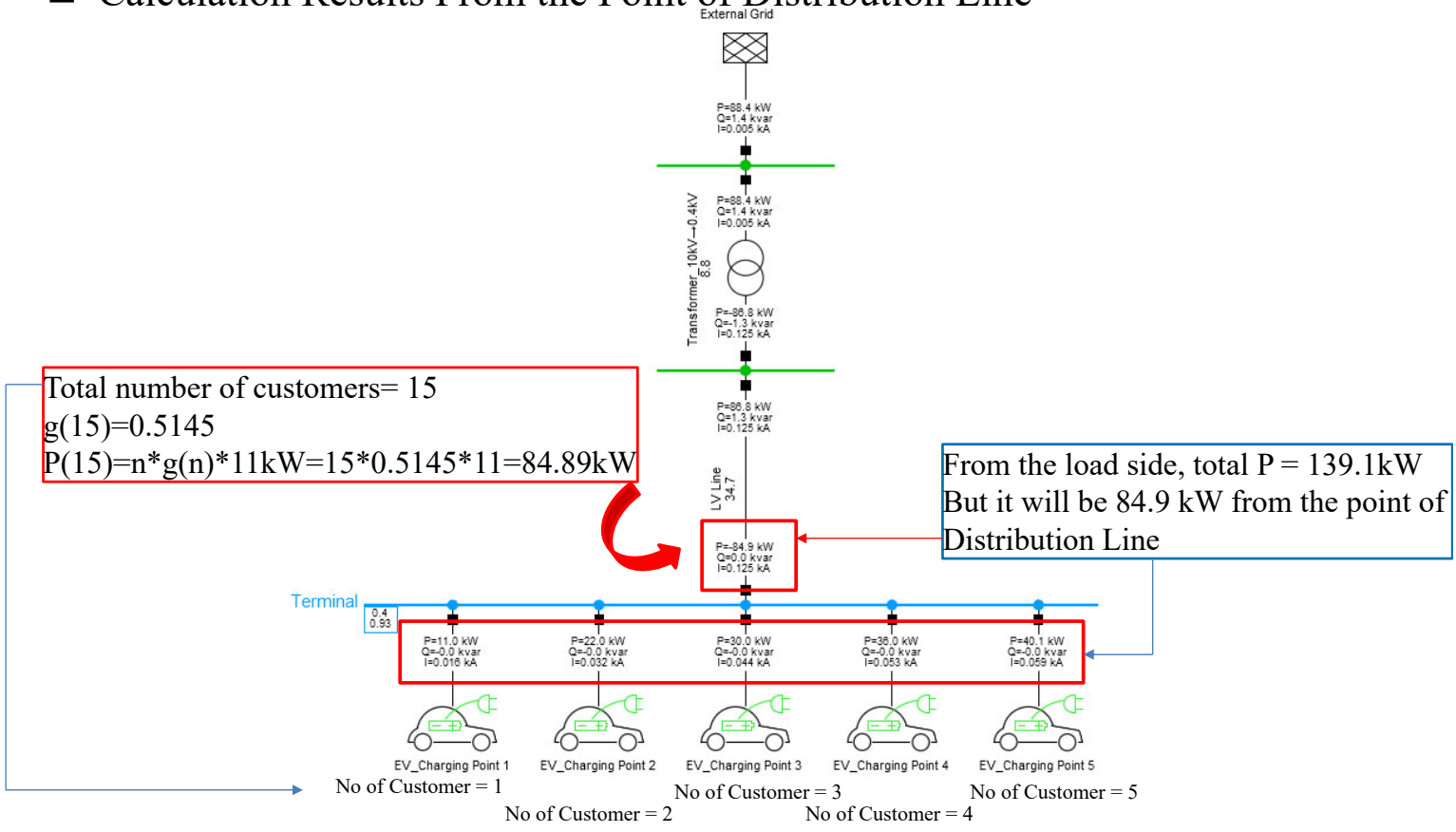
3.1 Coincidence Factor of EV Charging Points

■ Calculation Results : EV Charging Station (No of Customer = 5)



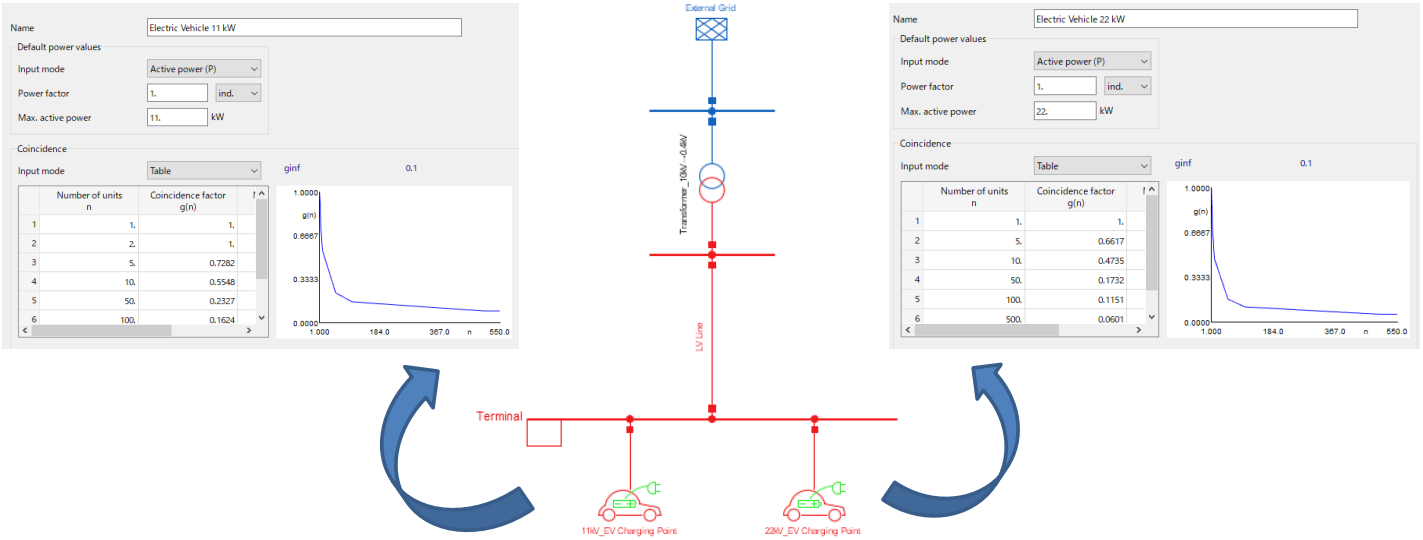
3.1 Coincidence Factor of EV Charging Points

■ Calculation Results From the Point of Distribution Line



3.2 Coupling Effect

- By default, all coincidence curves are independent of each other, which means that the number of customers for all given curves is counted separately.
- However, a coupling between different load categories and their respective coincidence curves can be explicitly defined in the calculation command.
- This coupling definition can be used to define which load categories are mutually considered in the coincidence and which are not. That means the coupling of curves can be used if different types of curves shall have an impact on each other.
- In this case, coincidence curve of 11kV EV Charging Station and 22kV Charging Station will be considered for coupling.



3.2 Coupling Effect

	EV 11 kW	EV 22 kW
EV 11 kW	1	1
EV 22 kW	1	1

Matrix with mutual consideration of coupling effect

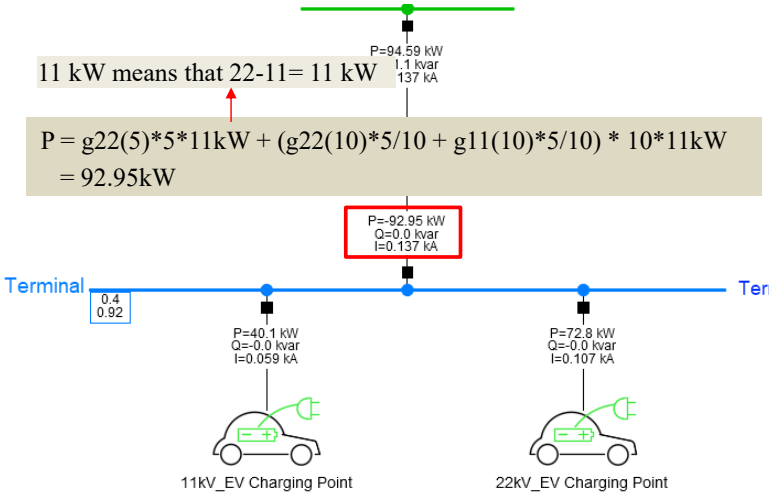
	EV 11 kW	EV 22 kW
EV 11 kW	1	0
EV 22 kW	0	1

Matrix without mutual consideration of coupling effect

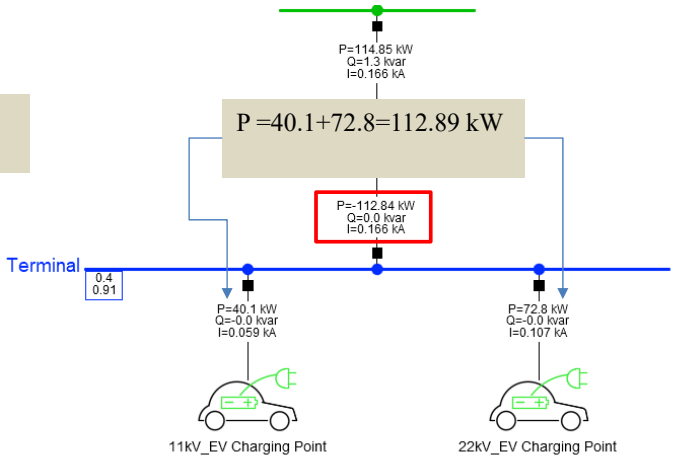
- Only values in the range 0 to 1 are allowed.
- Zero stands for no consideration and one for full (completely) consideration.
- Intermediate values are also possible, a value of 0.5, for example, means that only half the number is considered.

3.2 Coupling Effect

- Comparing Results of Low Voltage Load Flow Calculation with Applying Coupling Effect and without



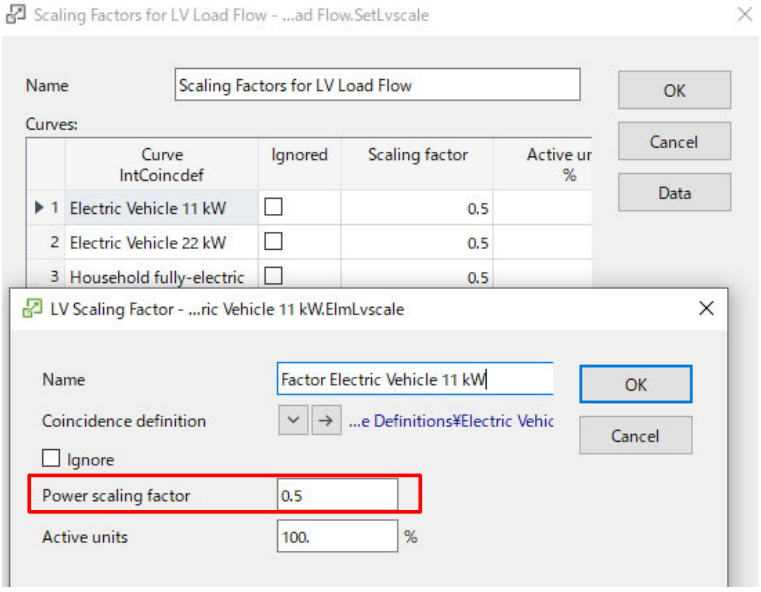
Result with Coupling Effect

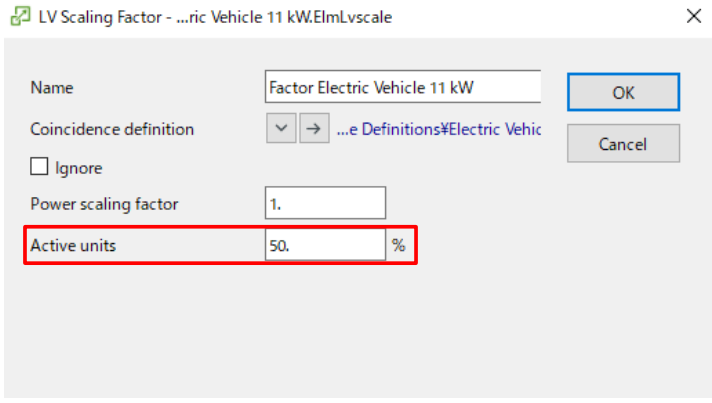


Result without Coupling Effect

3.3 Scaling Factor and Active Units

- Scaling Factor
  - By changing the Scaling Factor, the power of all components using the coincidence curve is directly Adjusted.
  - For example, the original active power of the component is 30 kW and the scaling factor is set to 0.5 and the actual active power of the component will be 15 kW
- Active Units
  - Changing the percentage of Active Units influences the consumed power by changing the number of considered customers. If the Active Units of the demand element is set as 50%, the number of customers will be reduced to half.

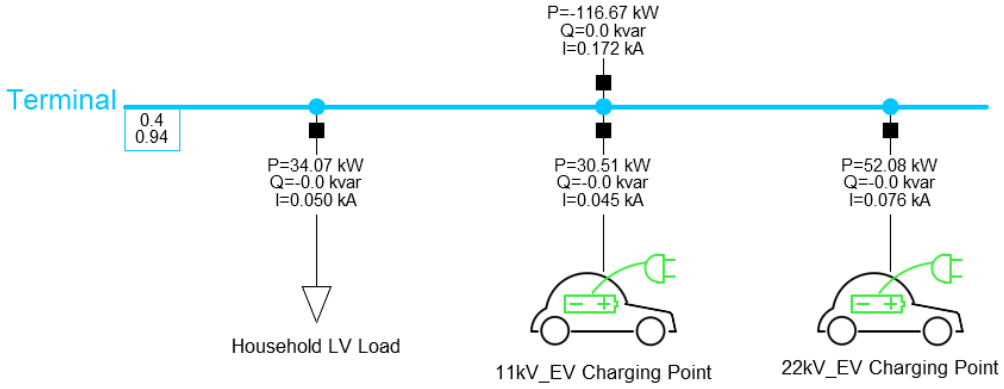




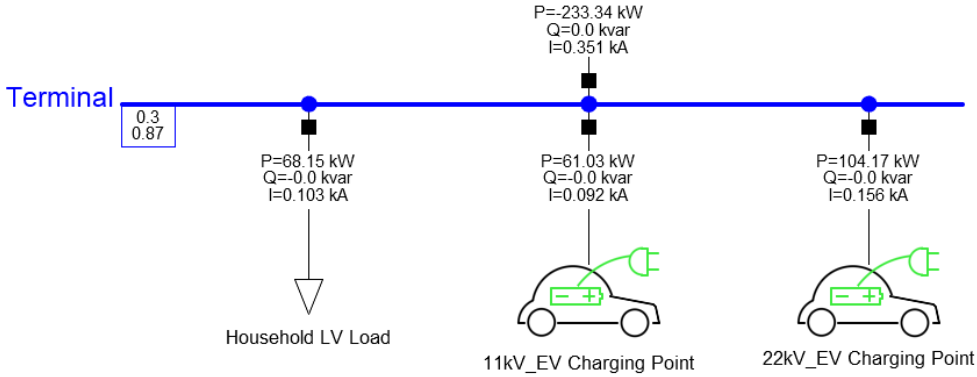
3.3 Scaling Factor and Active Units

- Load Flow Calculation Results of Scaling Factor _0.5 and Scaling Factor _1

Scaling Factor_0.5



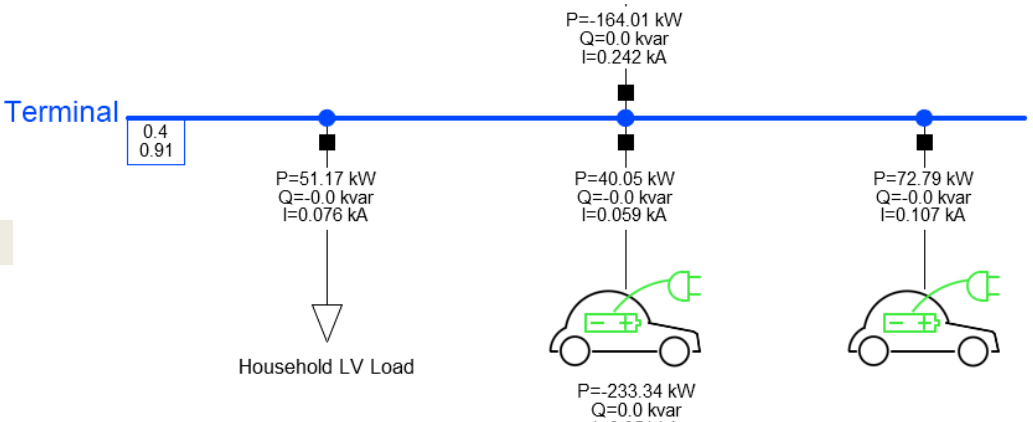
Scaling Factor_1



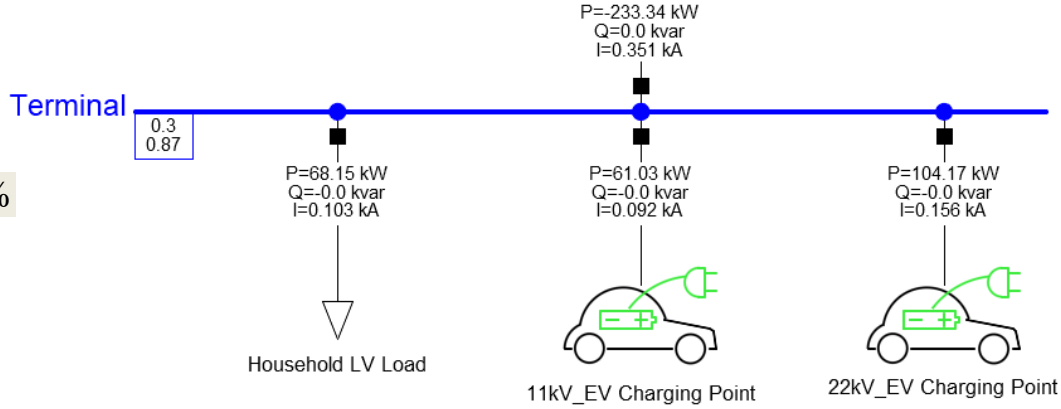
3.3 Scaling Factor and Active Units

- Load Flow Calculation Results of Active Units _50% and Active Units _100%

Active Units_50%

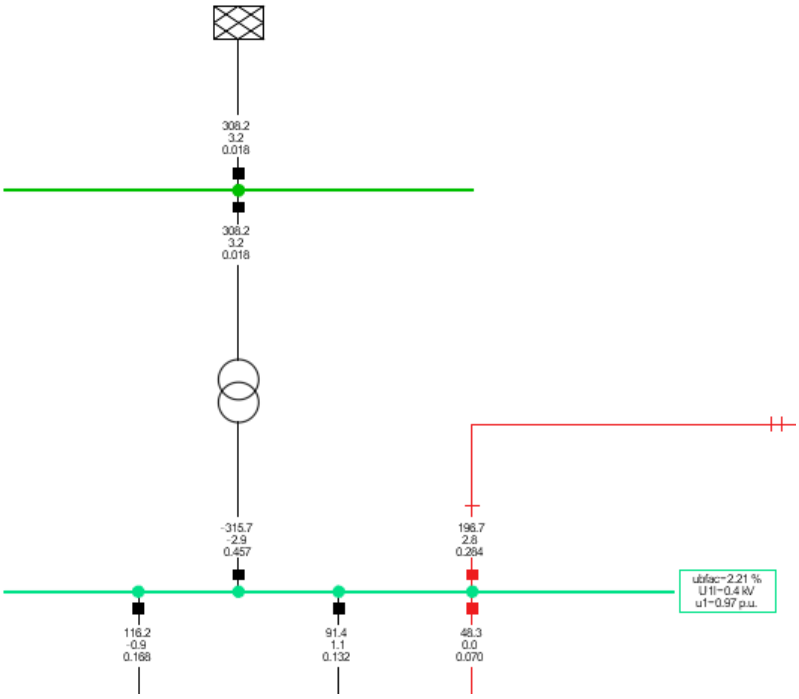


Active Units_100%



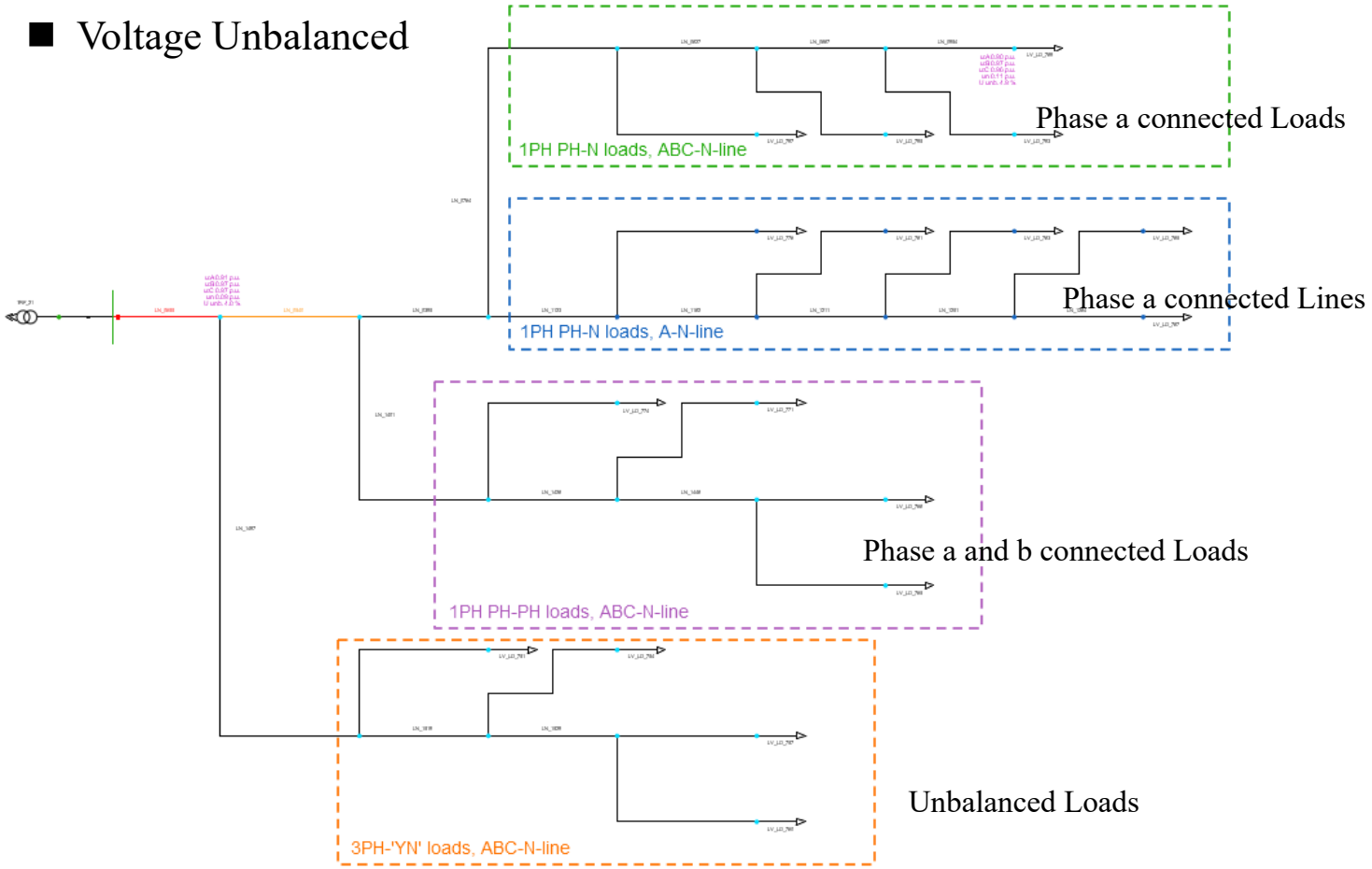
3.4 Analysis of Voltage Profile in EV Distribution Network

- Voltage Unbalanced

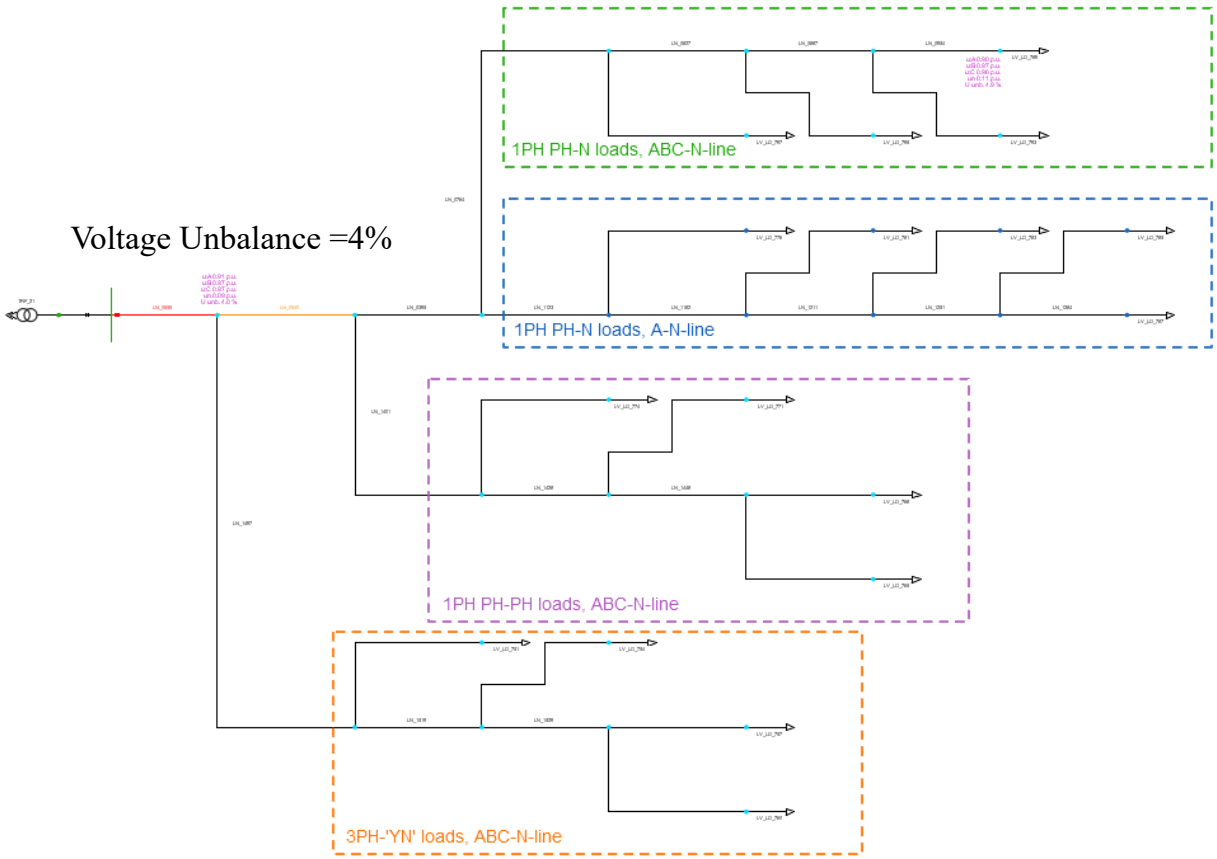


3.4 Voltage Unbalanced Load Flow

- Voltage Unbalanced



3.4 Voltage Unbalanced Load Flow



Presentation Material 2- 4

Activity 2-2-3 Identify the Issues on the Power Distribution System in the Connections of IRVE in Tunisia

Identify the Issues on the Power Distribution System in the Connections of IRVE in Tunisia

Activity 2-2-3, 2-4-2

JICA Expert Team

February 2025

Japan International Cooperation Agency
Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-2-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

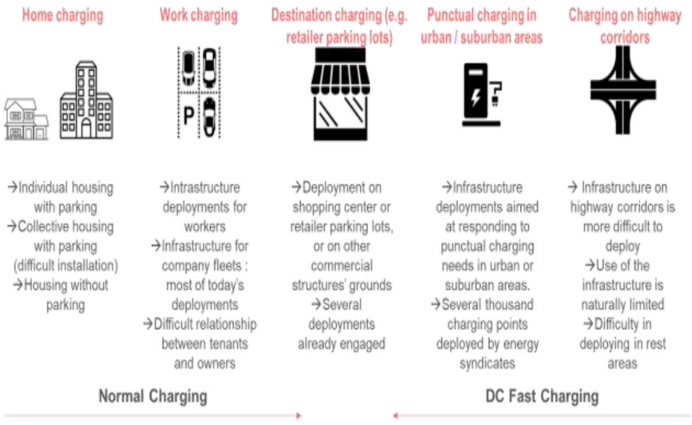
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1. Benchmark on the Connectivity

1.1 IRVE Connectivity: Insights from Japan

- **Charging Infrastructure and EV Adoption**: The expansion of **EV charging infrastructure** is vital to increasing EV adoption, especially in urban areas where **home charging** isn't feasible. Public charging networks become essential in these regions.
- **Types of EV Charging**: Charging services are categorized into three types:
  - **Basic Charging**: Charging at homes, apartments, and monthly parking lots.
  - **Destination Charging**: Charging at locations like shopping malls, hotels, and other destination points.
  - **Route Charging**: Charging at expressway **Service Areas (SAs)**, **Parking Areas (PAs)**, rest stops, and convenience stores along highways.



The main types of electric vehicle charging

Source: Analyses Electric vehicle charging infrastructure, Coda Stratégies, 2019

1.1 IRVE Connectivity: Insights from Japan

- **Connectivity Challenges in High-Density Areas**: In regions like **Asia**, where home charging isn't an option for many, **public charging networks** play a pivotal role. Unlike Western countries, these regions face unique connectivity challenges that require tailored solutions.
- **Global Leaders in Charging Infrastructure**:
  - **Norway**: Leads with the highest **EV market share** due to strong public policies and incentives.
  - **California**: Known for its ambitious **EV adoption goals**, supported by collaboration between public and private sectors.
  - **Japan**: Boasts an extensive and efficient **charging network**, achieved through successful public-private partnerships.
- **Best Practices**: The successful experiences from regions like **Norway, California, and Japan** offer valuable insights and best practices to help other countries, such as **France**, enhance their **EV charging networks** and improve global **IRVE** connectivity.

1.2 Global Strategies for IRVE Expansion

■ Japan's Strategy for Expanding IRVE Charging Infrastructure

- Japan targets 40% EV sales by 2030, with a solid public-private partnership supporting this goal. Currently, there is one charging point for every 4,125 EVs and PHEVs, with stations placed every 10 km² in urban areas and 30 km apart on highways.
- **Expansion Plans:** Japan plans to add 5,000 new charging points, focusing on underserved areas, highway rest stops, and private car parks in collective housing.
- **Nippon Charge Service (NCS):** The NCS consortium, including car manufacturers and energy firms, ensures nationwide roaming, affordable charging, and maintains both public and private stations.

■ Expanding EV Infrastructure Connectivity in California

- California's EV charging network has expanded from home charging to workplace and commercial spaces, bolstered by public incentives.
- **Early Investments:** Over 12,500 charging points were installed, supported by increased electricity tariffs.
- **Future Focus:** The state is now prioritizing fast-charging corridors, especially in collective housing, and working on developing controllable charging points to manage energy peaks and control consumption.

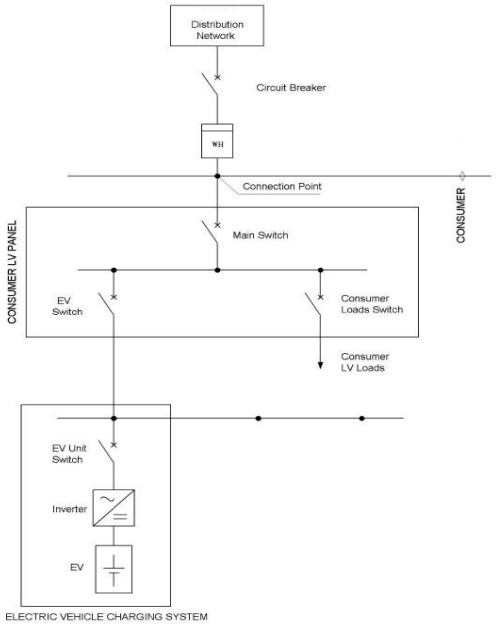
1.2 Global Strategies for IRVE Expansion

■ Expanding Norway's IRVE Charging Network Connectivity

- Norway leads globally with over 40% of vehicles being electric or hybrid, supported by strong government incentives and expanding IRVE infrastructure.
- **Private Sector Involvement:** While initially funded by the government, private companies now lead the development of IRVE charging stations.
- **Home Charging:** 97% of single-family homeowners rely on home charging. The next focus is improving access for apartment dwellers.
- **Future Focus:** Norway aims to expand fast-charging networks and introduce flexible pricing models to accommodate increasing demand.

1.3 Dedicated Connections for Individual Residents

- In some multifamily residences, **individually assigned charging units** offer a convenient solution for residents who wish to charge their electric vehicles (EVs) directly from their own electrical panel.
- **Installation and Cost**
  - Residents bear the cost of installing a **240VAC outlet** or charging unit.
  - Ensures that the electricity required for charging is drawn from the resident's own living unit.



Schematic Diagrams for Connection of Unidirectional IRVE to LV Distribution Network

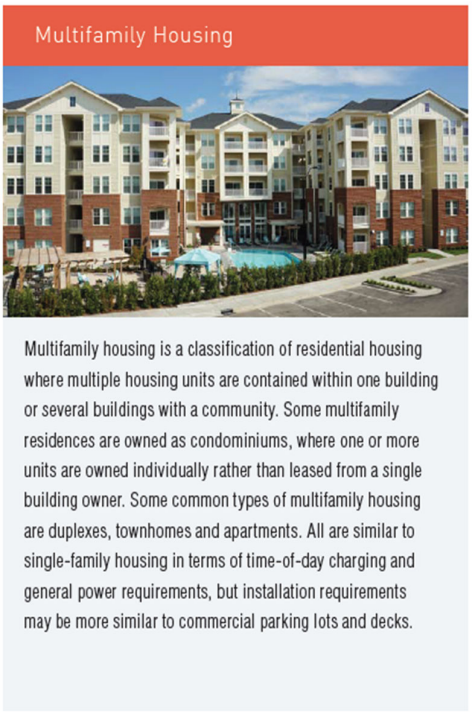
Source:This is a General Scheme

1.3 Dedicated Connections for Individual Residents

- **Direct Billing**
  - The **utility company** directly bills the resident for the electricity consumed during charging.
  - Charging unit may be metered separately or included in the existing unit meter.
- **Security and Accessibility**
  - Access to the charging unit can be restricted to prevent unauthorized use.
    - Options include mechanical/electronic locks or a **removable charging unit**.
- **Installation Locations**
  - Charging units can be installed in an **assigned parking space** or a **shared common area**, offering flexibility for both individual and shared usage scenarios.

1.4 IRVE Connectivity Challenges for MUD

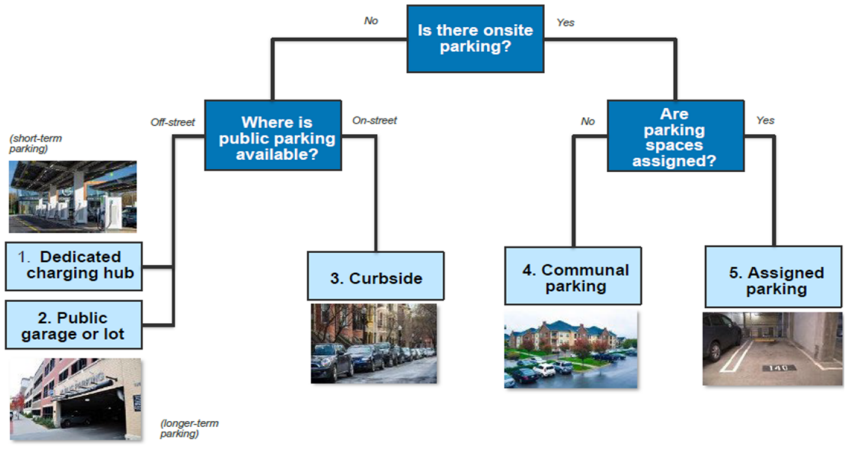
- **Installation Challenges:** In collective housing with dedicated parking, installing IRVE charging points can be difficult due to insufficient infrastructure. While residents can request installations, the process is often costly and time-consuming.
- **Cost of Electrical Upgrades:** As more residents adopt EVs, upgrading electrical systems to support additional chargers becomes expensive. This issue is especially tough for smaller co-ownership groups, where costs can be overwhelming.



Source: Plug-in Electric Vehicle Charging Infrastructure Guidelines for Multi-unit Dwellings, California Plug-In Electric Vehicle Collaborative, 2013

1.4 IRVE Connectivity Challenges for MUD

- **Limited Support from Co-ownership Bodies:** Co-ownership bodies, which could assist in managing the installation process, currently lack the necessary resources and knowledge.
- **Legal Reforms:** Legal reforms are expected to streamline the process, reducing organizational and time-related barriers, and facilitating the adoption of EV charging connectivity in residential complexes.



Types of parking available to multifamily residents.

Source: U.S. DOT Volpe Centre.

1.4 IRVE Connectivity Challenges for MUD

- **On-Demand Charging for Urban Households Without Parking**
  - Public on-demand charging points are critical for urban households lacking private parking.
  - Municipalities face challenges in providing accessible, affordable charging infrastructure to support electric mobility in these areas.
- **Economic and Practical Benefits of On-Demand Charging**
  - On-demand charging stations offer a practical solution by providing access to charging without exclusive rights.
  - This model reduces reliance on heavy financial incentives, as high usage rates contribute to economic sustainability.
  - Stations support grid management by enabling regular, overnight charging rather than fast charging.
- **Curbside Charging for Multifamily Residents**
  - Curbside or on-street parking charging solutions provide a cost-effective way to support multifamily residents in urban areas.
  - Low-power, overnight charging using existing streetlights or utility poles offers a simple and affordable solution for urban residents.

1.4.1 Overcoming Connectivity Challenges for MUD

- **General Challenges**
  - **Electrical Infrastructure Issues**: MUDs often lack the capacity to support the high demands of EV charging.
    - Upgrades to transformers, switchboards, wiring, and panels are usually required.
    - These upgrades can be costly and may involve coordination with local utilities.
  - **Garage Setup Limitations**: Garages are typically designed for basic functions, meaning substantial upgrades may be necessary for EV chargers.
- **Infrastructure Challenges**
  - **Capacity Constraints in Electrical Systems**
    - MUDs were not designed for the electrical load of EV chargers, requiring expensive upgrades.
    - Some energy efficiency retrofits may increase capacity but come with added costs.
  - **Space Limitations in Parking Areas**
    - Limited space for installing EV chargers in MUDs.
    - Shared chargers in common areas can lead to scheduling conflicts.
    - Individual chargers may require more space, especially in high-density areas.
  - **Optimal Location for Installations**
    - Charging stations should be located near existing electrical connections to reduce installation costs.

1.4.1 Overcoming Connectivity Challenges for MUD

- **Electrical System Upgrades**
  - Complex and costly upgrades may include drilling through garage walls and parking decks.
  - Surface-mounted conduits offer a more affordable and visually acceptable solution.
- **Transformer Upgrades**
  - Local utilities assess whether the existing transformer can support added EV chargers.
  - If an upgrade is needed, the utility works with property owners to determine costs and ensure regulatory compliance.

Cost and Billing Solutions

- **High Installation and Ongoing Maintenance Costs**
  - Initial setup and long-term maintenance of EV chargers can be expensive for property owners and residents.
  - Cost-sharing models or third-party operators may help alleviate financial burdens.
- **Billing and Cost Management**
  - **Smart Meters** track energy consumption for fair billing based on actual usage.
  - **Flexible Billing Models** (time-based or energy-based) ensure equitable costs for shared charging setups.
  - **Payment Systems** may integrate with mobile apps or subscription models for better convenience and transparency.

1.4.1 Overcoming Connectivity Challenges for MUD

Design and Usage Considerations

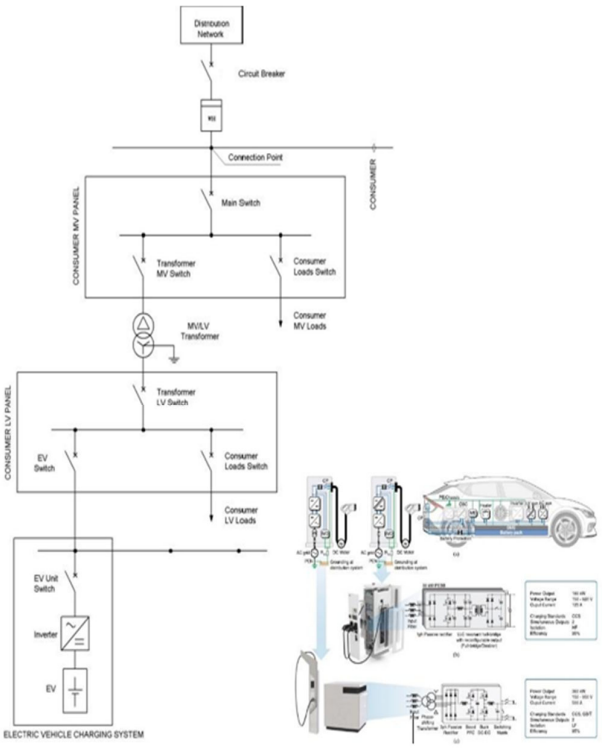
- **Impact of Parking Arrangements on IRVE Solutions**
  - The type and location of parking arrangements significantly affect EV charging integration in MUDs.
  - Options include curbside charging, off-street shared chargers, and assigned parking spots, each requiring different strategies.
- **Charging Solutions for Shared Parking**
  - In communal parking, off-street charging stations can be shared by residents.
  - **Resident Surveys** help determine the number of chargers and optimal locations.
  - **Mobile Charging or Valet Services** may help overcome infrastructure limitations.
- **Charging Solutions for Assigned Parking Spaces**
  - Assigned parking makes it easier to install individual chargers, enabling slower, overnight charging without conflicts.
- **Design Considerations for IRVE in MUD Public Parking Lots**
  - Public garages require specialized design strategies, such as:
  - **Wall or ceiling-mounted chargers**
  - **Solar canopies with battery storage**
  - **Strategic placement** near entrances or elevators to encourage usage.

1.4.1 Overcoming Connectivity Challenges for MUD

- **Technology and Smart Infrastructure Solutions**
  - **Utilizing Smart Outlets and Panels**
    - **Smart Outlets** convert existing household outlets into metered EV charging points, offering a more affordable solution.
    - **Smart Panels** track electricity usage at the circuit level, improving overall system efficiency and monitoring.
- **Utility and Community Support**
  - **Utility Support through Make-Ready Programs**
    - Utility companies offer **make-ready programs** to cover necessary upgrades (e.g., wiring and panel installations).
    - **Cost Recovery Mechanisms** ensure equitable financial responsibility.
    - Programs may include **TOU rates**, **load management**, and **demand response** technologies to optimize electricity usage.
  - **Legal, Regulatory, and Community Barriers**
    - MUD owners and residents often need approval from **homeowners' associations (HOAs)** or co-owners, which can be a complex process.
    - Local regulations may impose **zoning restrictions** or require **environmental assessments**, creating additional installation barriers.

1.4.2 Supporting IRVE Charging in MUD

- Electrical systems include various components designed to **manage power distribution** and meet the increased demand for EV charging.
- **Key Electrical Components**
  - **Main Transformer**
    - Reduces **voltage** from the utility's distribution system to building-level voltages.
    - Small buildings typically use **120/240V**, while larger buildings may use **277/480V**. Larger buildings might have **their own transformers**.
  - **Main Electrical Meter**
    - Measures **total electricity consumption**.
    - Additional meters or **sub-meters** may track energy usage for **EV chargers** or individual units.



Off-board dc chargers. (a) Typical configurations with isolation at HF and LF.

Schematic Diagrams for Connection of Unidirectional IRVE to MV

Source: Rivera et al.: Charging Infrastructure and Grid Integration for Electromobility

1.4.2 Supporting IRVE Charging in MUD

- **Switchgear**
  - Used in **larger buildings** to control and protect electrical equipment.
  - Ensures **effective power distribution** across various building sections.
- **Feed Transformers**
  - **Step down voltage** to provide power to specialized equipment like **EV chargers**.
- **Branch Panels**
  - Distributes power from the main system to specific sections of the building, including **resident parking areas** where EV chargers are located.
- **Branch Circuits and Outlets**
  - Provide power to devices such as **EV chargers**, either through **receptacles** or direct **hardwiring** into the system.

1.4.3 Metering and Billing Solutions for Charging in MUD

Choosing the Right Metering Solution

- Essential for fair billing and efficient energy management when integrating EV charging in multifamily housing.
- Several metering options, each with benefits and challenges.

Metering Options

- **Residential Metering**
  - Each resident has a **dedicated meter** to track individual energy usage.
  - Provides **accurate tracking**, but may not be cost-effective due to installation and maintenance costs.
- **Master or Group Metering**
  - **Single meter** measures electricity for the entire building.
  - Simplifies installation but complicates tracking individual energy use for EVs, making cost allocation more challenging.



Specific Meters in a MuD

Source: Plug-in Electric Vehicle Charging Infrastructure Guidelines for MUD, California Plug-In Electric Vehicle Collaborative, 2013

1.4.3 Metering and Billing Solutions for Charging in MUD

- **Sub Metering**
  - **Sub meters** allow for individual billing, addressing cost-sharing issues.
  - Encourages EV adoption with **fair and transparent charges**.
- **Common Area Metering**
  - **Shared electricity** for spaces like parking lots is measured collectively.
  - Cost-effective but poses challenges for tracking specific energy usage for individual EVs.

Payment and Access Models

- **Access via Subscription, ID Card, or Credit Card**
  - PEV drivers access chargers through **subscription services**, **electronic ID cards**, or **credit cards**.
  - Payment models may include **flat monthly fees** for unlimited access or **pay-per-use** based on electricity consumption.

Billing and Cost Management

- **Intermediary Billing**
  - Property owner or HOA may act as an intermediary between the **PEV owner** and the **EV service provider (EVSP)**.
  - Billing can be done directly to the **PEV owner** or integrated into the **property management billing cycle**.

1.4.3 Metering and Billing Solutions for Charging in MUD

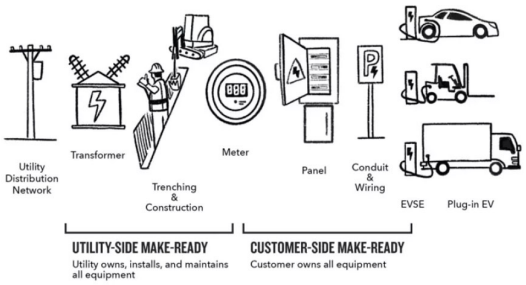
Advanced Technology Integration

- **Efficient Tracking and Billing**
  - Advanced systems offer **better tracking and billing** functionalities for efficient cost management.
  - **New technologies** allow local controllers (e.g., touch screens or networked devices) to manage access and payments, even for non-networked units, requiring **user credentials** for secure access.

1.4.4 Make-Ready Programs: Enhancing IRVE in MUD

- **Make-Ready Programs**
  - Utility companies support MUD charging infrastructure through **"make-ready" programs**, upgrading electrical systems for future EV chargers.
  - These programs help **reduce future installation costs**.

- **Utility Make-Ready Programs**
  - **Utility-Side Make-Ready Infrastructure**
    - Covers costs related to **adding new electrical service** and **installing electrical meters**, typically funded by the utility company.



Utility-side and customer-side make ready infrastructure.
Source: NRDC. 2021

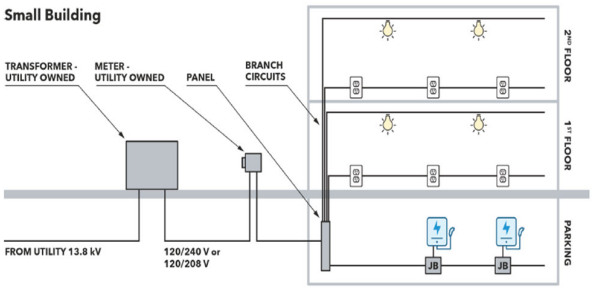
  - **Customer-Side Make-Ready Infrastructure**
    - Property or unit owners are responsible for installing **IRVE (Electric Vehicle Supply Equipment)** like **EV-ready outlets** on their properties.

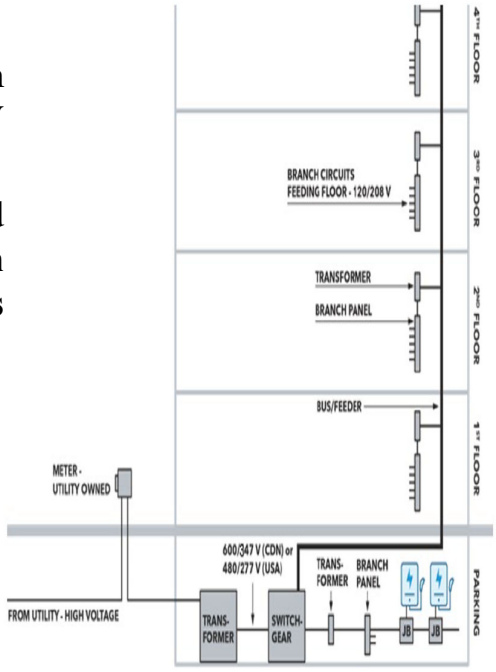
- **Streamlining the Process**
  - Utility Make-Ready Programs simplify the process of equipping multifamily properties with **EV charging capabilities**, reducing adoption barriers.

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Four Connectivity Strategies for EV Charging**
  - There are four main strategies for futureproofing parking for EV charging: **EVSE Installed**, **EV Ready**, **EV Capable**, and **Conduit and Space**.

- **Key Considerations for Planning**
  - **Electrical Systems**: The building's electrical system must be properly sized to handle the added load of EV chargers.
  - **Existing Buildings**: Older buildings with limited spare capacity require a **thoughtful design approach** to avoid overloading and manage **installation costs** effectively.

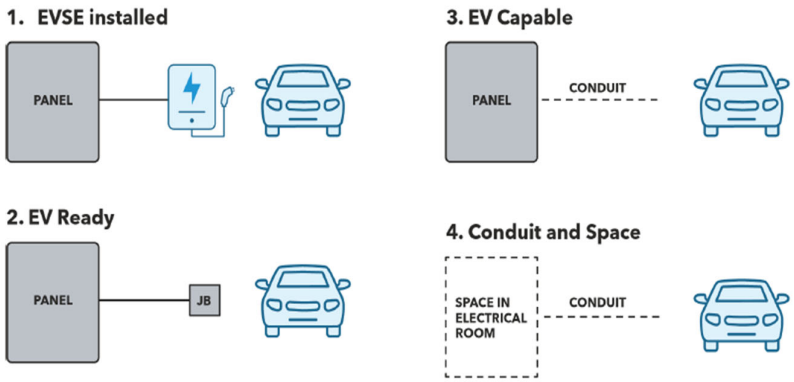




Electrical systems in a smaller building.
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Four Primary Connectivity Configurations Strategies:** for scalability and adaptability in EV charging infrastructure.
  - These strategies help property owners and developers prepare parking facilities for **future EV infrastructure**, reducing the need for expensive **retrofits** later.



Different ways to futureproof a parking space for EV charging.

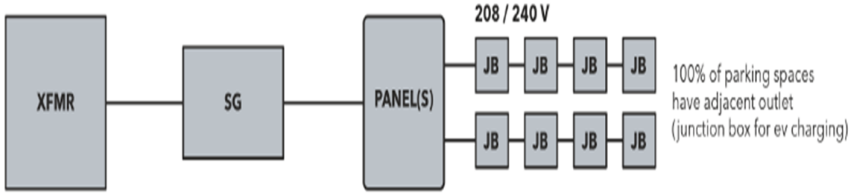
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **EVSE Installed**
  - **Fully installed** Electric Vehicle Supply Equipment (EVSE), including chargers, electrical panels, and wiring.
  - Provides **immediate functionality**, allowing residents or tenants to start using chargers right away.
- **EV Ready**
  - Parking spaces are equipped with the necessary **electrical infrastructure**, such as dedicated circuits.
  - Allows for **easy installation** of chargers when needed, without major upgrades.
- **EV Capable**
  - The building's electrical system is designed to **handle the future load** of multiple EV chargers.
  - Pre-wired with **sufficient capacity**, making it easier to add chargers as demand increases.
- **Conduit and Space**
  - Involves installing **conduit** and reserving **space** for future EVSE installation.
  - **Cost-effective approach**, ensuring easy installation later without requiring extensive renovations.

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **EV-100% Ready System:**
  - Level 2 Outlets for Efficient Load Sharing across multiple branch circuits.
    - Allows **several chargers to operate** on a single circuit, optimizing **energy distribution**.
  - **Load Distribution Management**
    - **Efficient load management** at both the service and feeder levels.
    - **Networked Level 2 chargers** can be used, but **non-networked options** reduce ongoing networking fees, making it more **cost-effective** for property owners.
  - **Benefits for Property Owners & Developers**
    - Ensures **EV infrastructure** is prepared for **future demand**.
    - **Minimizes costs** associated with future upgrades or retrofits.



100% EV Ready with Level 2 outlets designed for load-sharing on branch circuits.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Ensuring 100% EV Readiness with Level 2 Outlets and Feeder Monitoring**
  - **Comprehensive EV Readiness Solution**
    - Incorporates **Level 2 outlets** and **feeder monitoring** into the building's electrical infrastructure.
    - Links charging units directly to **residential panels** for **accurate billing** based on individual household energy use.
  - **Cost Savings & Efficiency**
    - Eliminates the need for **separate billing services**, reducing costs for both property owners and residents.
    - **Non-networked EVSE** reduces infrastructure costs while maintaining efficient charging.
    - If residents already have **Level 2 capable EVSE**, no need to purchase additional equipment, leading to **further savings**.
  - **Scalable & Economical Solution**
    - **Future-proofs** the building for increasing EV charging demand.
    - Offers a **cost-effective** and **scalable solution** for multifamily housing.

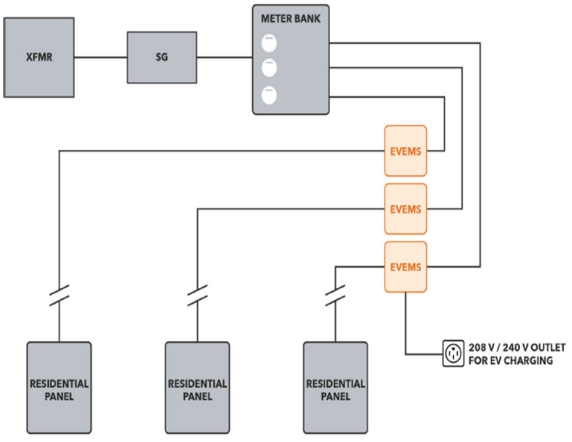
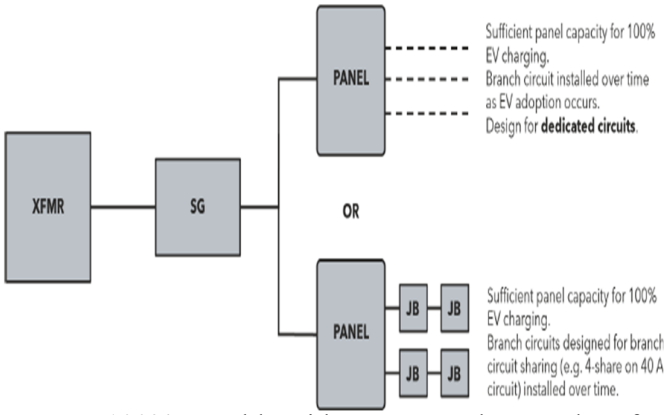


Figure: EV Ready with Level 2 outlets designed for feeder monitoring of residential unit's electrical panels.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Achieving 100% EV Capability with Incremental Branch Circuit Upgrades**
- **Two Primary Approaches involved for Upgrades**
  - **Dedicated Branch Circuits with Smart Panels**:
    - Smart panels provide **control** over branch circuits, allowing them to be **turned on/off as needed**.
    - Accommodates **cost-effective, unnetworked "dumb" EVSE**, helping to lower overall infrastructure costs.
  - **Load Sharing Across Branch Circuits**:
    - As EV adoption grows, **branch circuits are progressively upgraded** to support additional loads.
    - **Networked EVSE** units linked to **EVEMS** balance and optimize **energy distribution**, ensuring efficient **load management**.

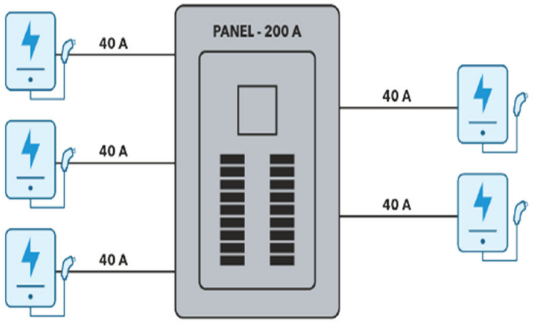


EV 100% Capable with Incremental Upgrades of Branch Circuits.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Dedicated Circuits for Electric Vehicle Supply Equipment (EVSE) Without Electric Vehicle Energy Management System (EVEMS):**
  - **Key Considerations**
    - Without **EVEMS**, electrical codes require **EVSE loads** to be designed near full panel capacity.
    - Example: A **200A panel** can support **up to five EVSE units** on **40A circuits**, each needing its own **dedicated branch circuit**.
    - **Sharing circuits** between multiple units is **not permitted**.
    - For **lower power charging** needs, the panel can also support **up to ten Level 1 outlets** with **20A breakers**.



Unmanaged Dedicated Circuit with no EVEMS.

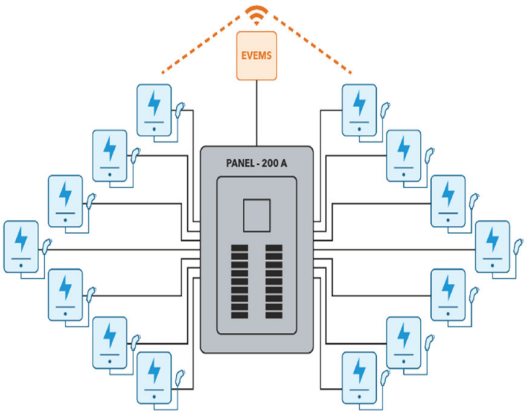
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

■ Effective Load Management with (EVEMS) Configurations

➢ Optimizing Load Distribution with Panel Sharing for EV Charging with EVEMS

- **EVEMS** helps control **charging load distribution**, preventing strain on the **branch panel** and **feeder**.
- **Networked EVSE units** are connected to **EVEMS**, enabling **efficient energy use** across multiple units.
- Integration with **branch circuit sharing** enhances **load balancing**, ensuring the system operates **efficiently** and reduces the risk of **overloads**.



Panel Sharing Using EVEMS.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

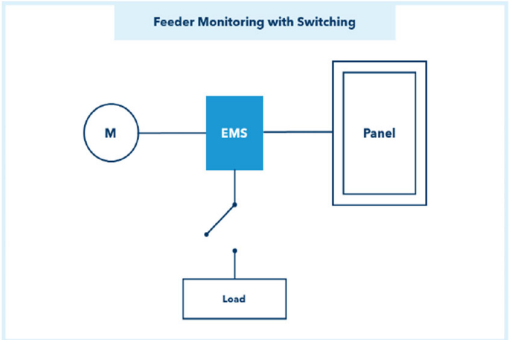
➢ Feeder Monitoring

- Continuously tracks **electrical consumption** of feeders supplying power to individual units.
- **Monitoring device** is placed between the **unit's meter** and **electrical panel** to track energy use.
- When consumption nears **feeder capacity**, the system can **disconnect** EVSE or **reduce power** by interacting with **networked chargers**.
- Best suited for **smaller to mid-sized properties** or **townhomes** due to challenges in high-rise buildings where meters are typically on upper floors.



Example of Multiple Feeder Monitoring Devices Installed on a Meter Stack Serving a Parking Garage.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023, Source : MURBLY / RVE.

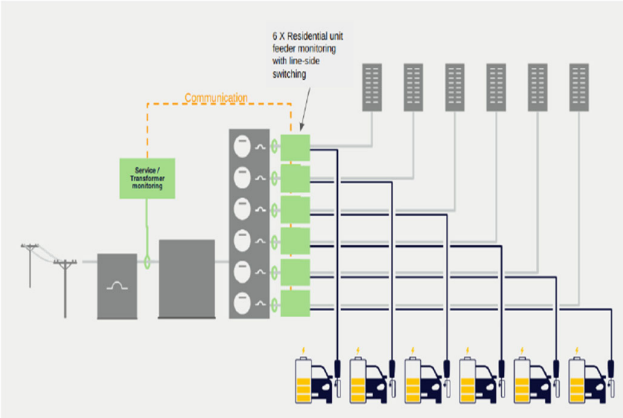


Feeder Monitoring with Switching.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.4.5 Parking Connectivity Strategies for IRVE in MUD

- **Optimizing EV Charging Load Management through Multi-Tier Monitoring**
  - **Feeder Monitoring** tracks **real-time power usage** at the **individual residential panel level**, ensuring efficient load management.
  - Monitoring devices installed at **key points** (main service panel/building transformers) track and control **total electrical load**, preventing overloads.
  - Devices communicate with **EV chargers** to ensure balanced power distribution.
  - **CE Code rule 8-106(11)** excludes EV charging loads from overall service and transformer load calculations, allowing for **design flexibility**.
  - Offers a **scalable, safe solution** for property owners and developers, ensuring electrical systems accommodate **EV charging demands**.



Service Monitoring with monitoring of units' electrical panels (a form of multi-tier monitoring). Source: RVE.

Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

1.5 Enhancing IRVE Accessibility at Highway in Japan

- **Case Study Overview**
  - **Enhancing IRVE Accessibility at Highway (SA/PAs) in Japan**
  - Examines EV charging services along Japan's expressways.
  - Focuses on the collaboration between expressway companies, EV charger installers, service providers, and network operators.
  - Includes six expressway companies and nine businesses involved in charging infrastructure, covering roles like installation, connectivity, service, and network management.



Example of a multi-port EV charger

Source: eMP submission materials

1.5 Enhancing IRVE Accessibility at Highway in Japan

- **Multiple Vehicle Charging**
  - Expressway Service Areas (SA/PAs) are equipped with chargers that can serve several EVs simultaneously.
  - Example: The Hamamatsu SA installation by eMP has chargers with up to six connectors, allowing for simultaneous charging of six vehicles.
- **Varying Power Outputs**
  - Charging stations offer a range of power outputs from 20 kW to 150 kW, depending on the charger's age and technology.
  - Newer chargers typically provide higher power for faster charging.
- **Connector Flexibility**
  - Each charging unit supports up to six connectors.
  - This flexibility helps manage demand, especially during peak times, allowing multiple vehicles to charge without delays

1.6 IRVE Connectivity on Expressways in Japan

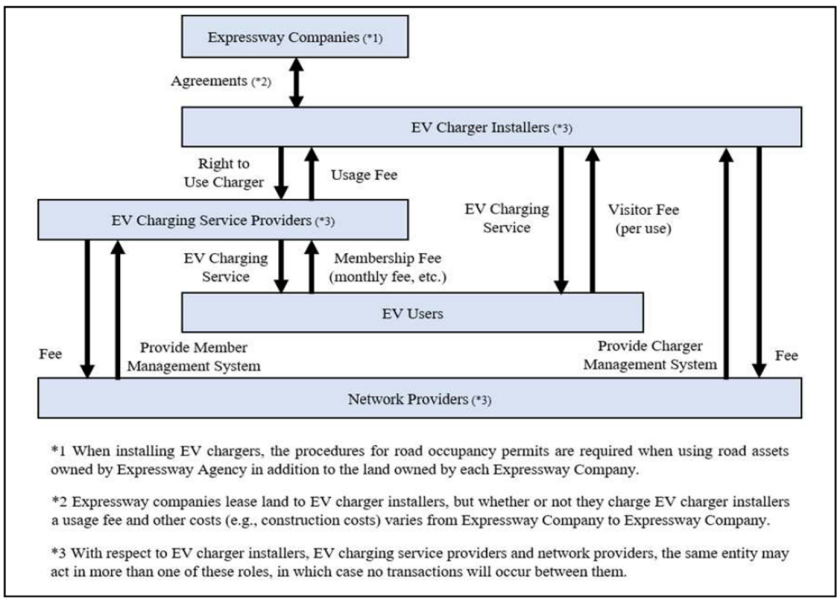
- **Expressway Companies and Expressway Agency**
  - **Role**: Responsible for constructing, operating, and maintaining Service Areas (SA) and Parking Areas (PA) along expressways.
  - The **Expressway Agency** owns the road assets and is an independent body.
  - **Land Use Permission**: Installing EV chargers requires permission from both the Expressway Agency and expressway companies.
- **EV Charger Installers**
  - **Role**: Fund, install, and operate EV charging stations at Expressway SA/PAs.
  - They may charge other companies for access and set fees for non-member drivers.
  - **Notable Companies**: Key players in rapid charger installation include:
    - e-Mobility Power Corporation
    - ENEOS Corporation
    - PLUGO, Inc.
    - Newer entrants like Ubiden, Inc.
- **EV Charging Service Providers**
  - **Role**: Offer access to chargers via a membership system.
  - Members typically receive charging cards, and the service charges a monthly fee plus pay-per-use rates.
  - **Key Providers**: Major providers include automobile manufacturers, ENEOS Corporation, and PLUGO, Inc.

1.6 IRVE Connectivity on Expressways in Japan

- **Network Providers**
  - **Role**: Manage the charging systems, overseeing power usage, billing, and member management for service providers.
  - They ensure the smooth operation of the charging infrastructure.
  - **Fee Structure**: Network providers charge a variety of fees, including monthly and usage-based charges.
- **Key Players**: Prominent network providers include:
  - Enegate Co., Ltd.
  - TOYOTA Connected Corporation
  - NEC Corporation
- **Standardization Efforts**: Network providers work to standardize communication protocols for seamless integration across charging systems.
- **Key Example**: eMP acts as both charger installer, service provider, and network provider.

1.7 Streamlining Connectivity and Payment Systems

- **Transaction Flow for Charging at Expressway Service Areas**
  - Insights into typical transactions at expressway Service Areas (SAs) and Parking Areas (PAs) for EV charging.
  - Highlights any variations, providing a clearer understanding of how these interactions unfold.



Business relationships for EV charging services at Expressway SA/PA.

Source: Compiled by the JFTC from the results of the hearings with each company

1.7 Streamlining Connectivity and Payment Systems

■ Charging Card Requirement for Access

- Drivers need a **Charging Card** linked to their credit card for access and payment.
- These cards enable seamless transactions at the charging stations.

■ Service Providers

- Major car manufacturers and companies like **Toyota**, **Nissan**, **Honda**, **BMW**, and **eMP** issue Charging Cards.
- Charging payments are made through a combination of monthly memberships and per-use charges via credit card.

■ Payment Flexibility for Non-Members

- Non-members can still use chargers by paying with credit cards at designated verification points.

■ Future Expansion Plans

- NEXCO 3 (East, Central, and West Nippon Expressway Companies) are working with eMP to install around **1,100 charging sockets** by FY2025.
- eMP has already installed nearly **99%** of the EV chargers at Expressway SA/PAs, with ongoing installation and system upgrades.

1.7 Streamlining Connectivity and Payment Systems

■ Nippon Charge Service (NCS) Network Management

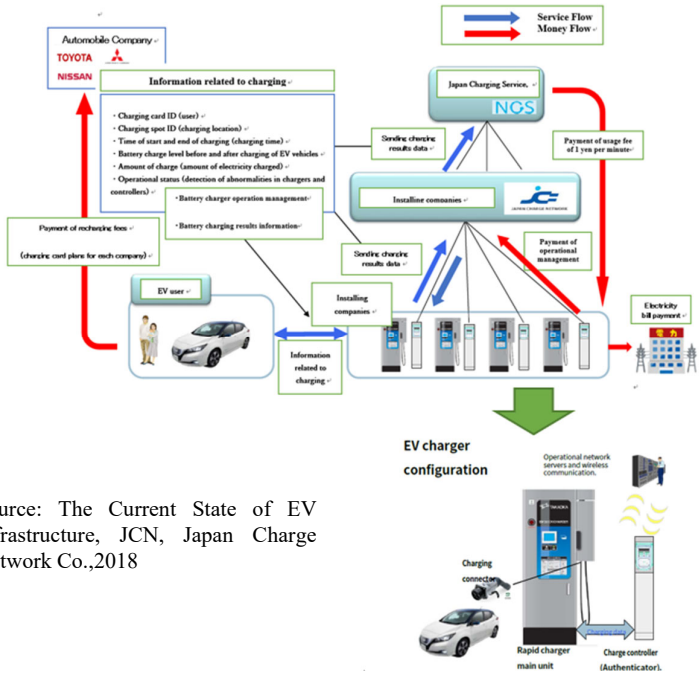
- NCS manages the nationwide network, ensuring a user-friendly experience for EV drivers.
- Allows charger installers to join and provides a unified platform for accessing all chargers within the network.

■ Unified Charging Card System

- A single **charging card** can be used across all chargers operated by NCS.
- Simplifies access to services at various locations for drivers.

■ Automaker Support

- Major automakers like **Toyota**, **Nissan**, **Honda**, and **Mitsubishi** support EV adoption by facilitating the development of a unified network.



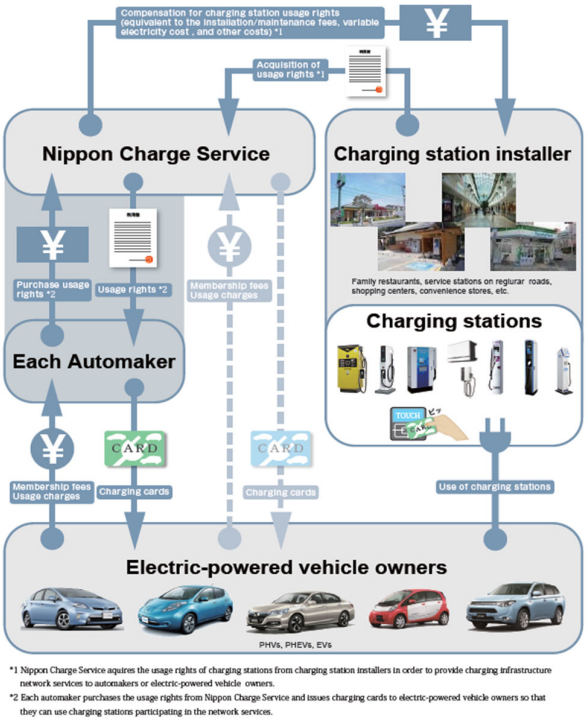
Source: The Current State of EV Infrastructure, JCN, Japan Charge Network Co.,2018

Schematic diagram of the charger operation business model

1.7 Streamlining Connectivity and Payment Systems

■ EV Charging System Process

- The charging process involves multiple steps with various stakeholders:
  - Data is transmitted from the charging station to an authentication device, then to a network server.
  - Companies like **Japan Charging Service (JCN)** calculate the charging fee and bill the EV user, often linked to the car manufacturer.
  - JCN ensures payment to the charging station operator for facility usage.



Outline of charging Infrastructure Network Services

Source: Japan Automakers Advance Electric Charging Infrastructure with New Company, Nippon Charge Service, 2014

1.7 Streamlining Connectivity and Payment Systems

■ JCN Network Management

- JCN manages both fast and regular charging networks at strategic locations like highways, convenience stores, and car dealerships.
- These stations are remotely monitored and gather key data:
  - User ID, charging location, session duration, energy consumption, and battery status.

■ Future System Efficiency Improvements

- Future models may shift to **time-based billing** instead of energy-based billing to encourage timely departure once the vehicle is fully charged.
- Introducing **online reservation systems** could optimize station usage and improve the user experience.

Presentation Material 2- 5

Activity 2-2-2-1 Simulation Methods for the Impact of EVs on the Electric Power Distribution System (Harmonic Analysis)

Simulation Methods for the Impact of EVs on the Electric Power Distribution System (Harmonic Analysis)

Activity 2-2-2-1

JICA Expert Team

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this presentation

WG	Activities		Activities	JICA expert	STEG	Time schedule
2	**2-1**		**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2	2-1-1		Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2	2-1-2		Introduction of case studies in Japan	✓		2nd
2	**2-2**		**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2	2-2-1		Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2	2-2-2		Lecture on simulation methods for the impact of EVs on the electric power distribution system(Coincidence Factor)	✓		3rd
2	2-2-2-1	A	Lecture on simulation methods for the impact of EVs on the electric power distribution system(Harmonic, voltage drop)			4th
2	2-2-3		Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2	2-2-4		Discussion on the issues and countermeasures	✓	✓	3rd
2	2-2-5		Create the conclusion report	✓	✓	6th-
2	**2-3**		**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2	2-3-1		Share the report of EV penetration scenario in Tunisia		✓	1st
2	2-3-2		Create/Assume a scenario of EV penetration	(✓)	✓	1st - 3rd
2	2-3-3		Lecture on the methodology for electricity demand forecast of EV in Japan	✓		4th
2	2-3-4		Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2	2-3-5		Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2	2-3-6		Report the comments to STEG	✓		5th
2	2-3-7		Discussion on the comments	✓	✓	5th
2	2-3-8		Improve the methodology	✓	✓	5th-

Contents

1. Overview
2. Purpose of Harmonic Analysis in Japan
3. Harmonic Regulations in Japan
4. Typical Types of Harmonic Analysis
5. Typical Analysis Workflow in Japan
6. Evaluation Criteria
7. Case Studies
8. Challenges & Considerations

1. Overview

Overview

- **H**armonic **A**nalysis is essential for maintaining Power Quality in modern electrical systems.
- With the rise of **inverter-based renewable energy** (PV, wind), **harmonics** have become a growing concern.
- In **Japan**, harmonic analysis has conducted **from industrial applications** to **large-scale renewable energy plants**.
- Emerging Challenge:
  - **Long-distance transmission cables** (tens of km) connected to **weak grids** can shift resonance to lower-order harmonics (e.g., 5^{th} , 7^{th}) leading to significant **voltage distortion.**

2. Purpose of Harmonic Analysis in Japan

Purpose of Harmonic Analysis in Japan

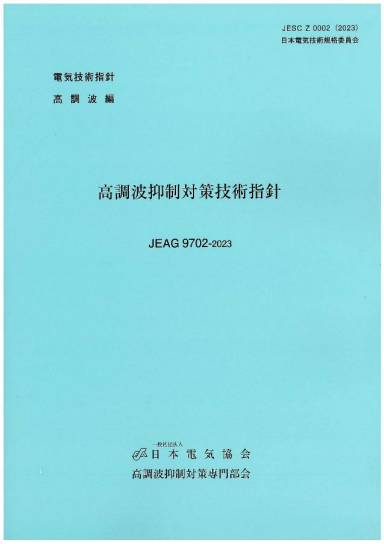
- Ensure grid compliance with grid connection standards and maintain overall power quality (remains within acceptable levels for all customers).
- Evaluate harmonic emissions from inverter-based generation (e.g., PV, wind)
- Identify risks of resonance and voltage distortion, especially in weak grids.
- Determine the need of harmonic mitigation measures (e.g., filters) in early project stages.
- Harmonic analysis is mandatory for grid interconnection applications.
  - Reviewed by regional transmission and distribution utilities
  - Applicants may be required to revise system design if emissions exceed limits

※*In Japan, each region has its own T&D utility responsible for grid operation and interconnection management.*

3. Harmonic Regulations in Japan

Harmonic Regulations in Japan

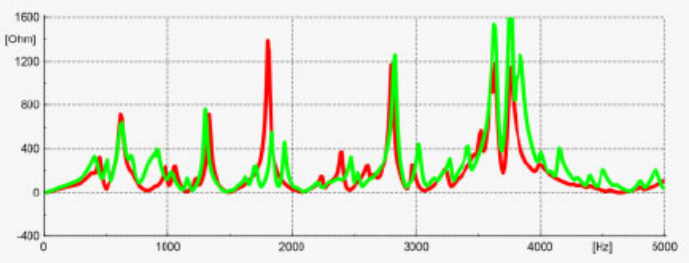
- Based on the “Technical Guidelines for Harmonic Suppression Measures”（高調波抑制対策技術指針）
- Issued by the Japan Electric Association (JEA)
- Defines limits for harmonic emissions and voltage distortion
- Referenced by utilities for grid interconnection approvals



4. Typical Types of Harmonic Analysis

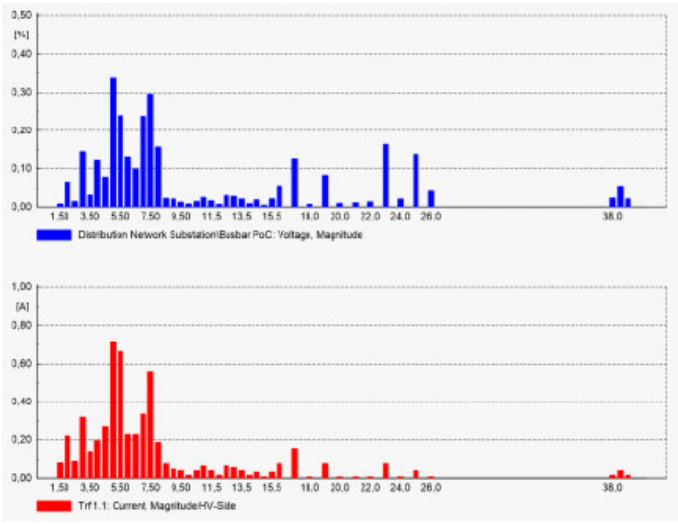
Typical Types of Harmonic Analysis

- **Frequency Sweep/Impedance**
  - ✓ Analyzes system impedance across frequency range
  - ✓ Identifies resonance frequencies where harmonic amplification may occur



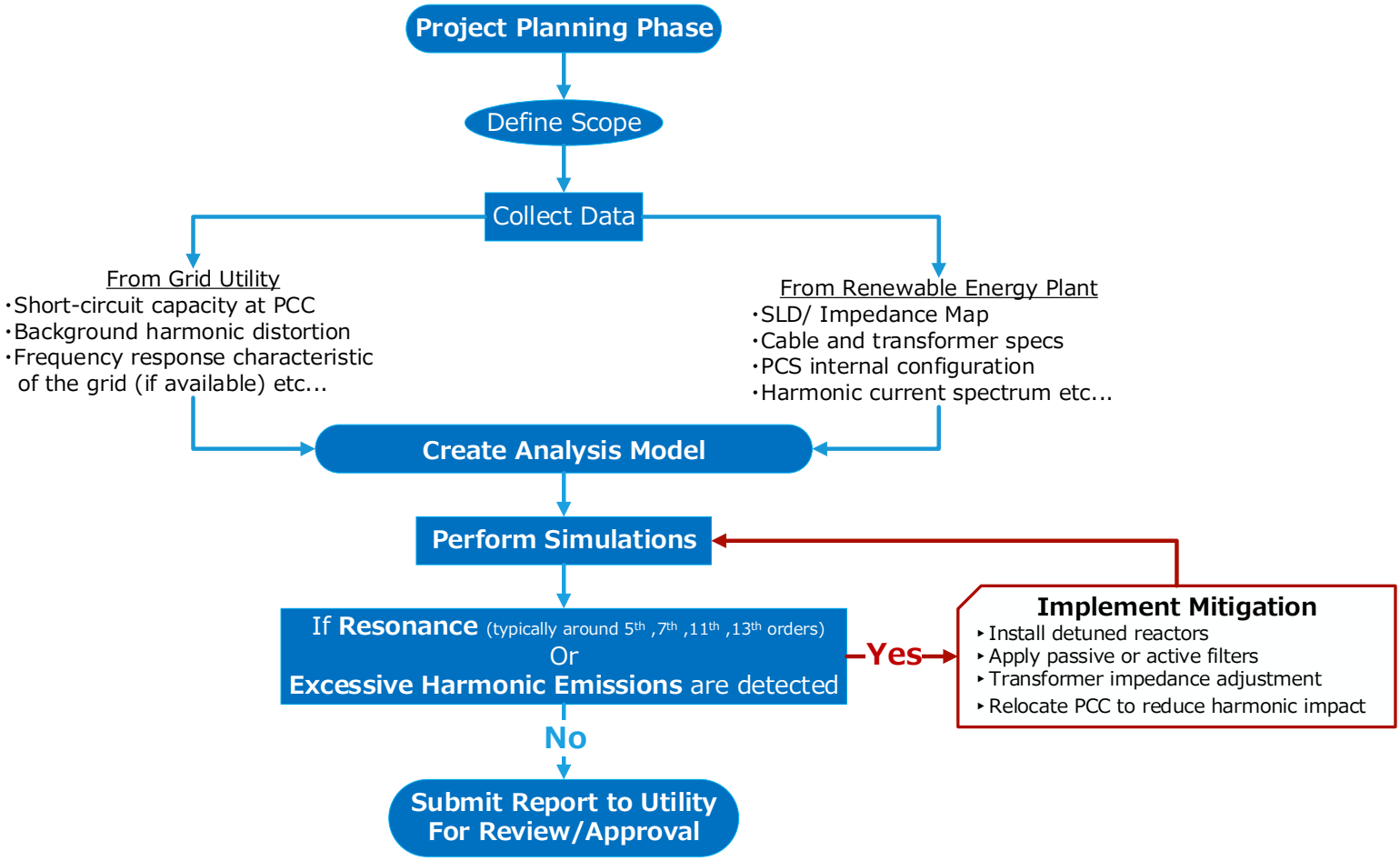
- **Harmonic Load Flow**
  - ✓ Calculate harmonic voltages and currents under normal operation
  - ✓ Evaluates individual harmonic orders and THD (Total Harmonic Distortion)
  - ✓ Requires harmonic source models (voltage or current injection)

$$\text{THD} = \frac{\sqrt{\sum_{n\geq 2} V_n^2}}{V_1} \times 100\ [\%]$$



5. Typical Analysis Workflow in Japan

Typical Analysis Workflow in Japan



6. Evaluation Criteria

Evaluation Criteria

- **Harmonic Resonance Risk**
  - ✓ Verify that no significant resonance occurs near dominant harmonic frequencies (e.g., 5^{th} , 7^{th} , 11^{th} , 13^{th})

- **Total Harmonic Distortion_THD**
  - ✓ THD is used as a measure of the amount of Harmonic distortion in the system.
  - ✓ Typically, below 3% at PCC (depends on voltage level)

$$THD = \frac{\sqrt{\sum_{n\geq 2} V_n^2}}{V_1} \times 100\ [\%]$$

V_n :RMS value of the nth harmonic voltage
V_1 :RMS value of basic voltage

Voltage Classification	Total voltage distortion factor
7kV~ Transmission System	3% (of the total)
~6.6kV Distribution System	5% (of the total)

THD Regulation in Japan

- **Point to Evaluation**
  - ✓ PCC or interconnection point with Utility to maintain power quality
  - ✓ Major buses within power plant site and PCS terminals to ensure proper PCS operation and prevent mis-operation of Ry.

※*Even under normal conditions, background harmonics of 2–3% may exist in the grid.*

Current Harmonic Emissions Regulations in Japan

- The amount of harmonic leakage is defined by the Japan Electrical Manufacturers' Association. The concept of setting the target limit value is as follows:
  - ✓ The average of harmonic emission in the whole country was derived from survey results of specific consumers.
  - ✓ The projected harmonic emission for specific consumers in FY2010 was **2.6 times** that of FY1987.
  - ✓ The target limit value is set to reduce the FY2010 emission to **half of its amount**, in order to maintain the future harmonic voltage distortion rate

- Harmonics Current Ratio of Fundamental Current Calculation
  - ✓ 6.6kV : 2.76 (%) × 2.6 × ½ =3.6 (%)
  - ✓ 22~ 33 kV : 3.77 (%) × same = 4.9 (%)
  - ✓ 66~77 kV: 5.15 (%) × same = 6.7 (%)

→ Distribution Voltage(~6.6kV)→3.6%
Transmission Voltage (22kV～)→6.7%

- <66 kV> Harmonic Current Emission per kW

①Fundamental Current(50Hz)
  - ✓ $1/(66kV \times \sqrt{3}) \times 10^3 = 8.75$ mA

②$5^{th}$ Harmonic Current
  - ✓ 8.75 mA × 6.7% =0.59 mA

③$7^{th}$ Harmonic Current
  - ✓ 0.59mA × $^5/_7$ = 0.42 mA

Current Harmonic Emissions Regulations

Target Limit Value of Harmonic Current Emission per kW of Specific Consumers

[Unit: mA/kW]

Voltage Level	5th order	7th order	11th order	13th order	17th order	19th order	23rd order	23rd over
6.6kV	3.5	2.5	1.6	1.3	1.0	0.90	0.76	0.70
22kV	1.8	1.3	0.82	0.69	0.53	0.47	0.39	0.36
33kV	1.2	0.86	0.55	0.46	0.35	0.32	0.26	0.24
66kV	0.59	0.42	0.27	0.23	0.17	0.16	0.13	0.12
77kV	0.5	0.36	0.23	0.19	0.15	0.13	0.11	0.10
110 kV	0.35	0.25	0.16	0.13	0.10	0.09	0.07	0.07
154 kV	0.25	0.18	0.11	0.09	0.07	0.06	0.05	0.05

7. Case Studies

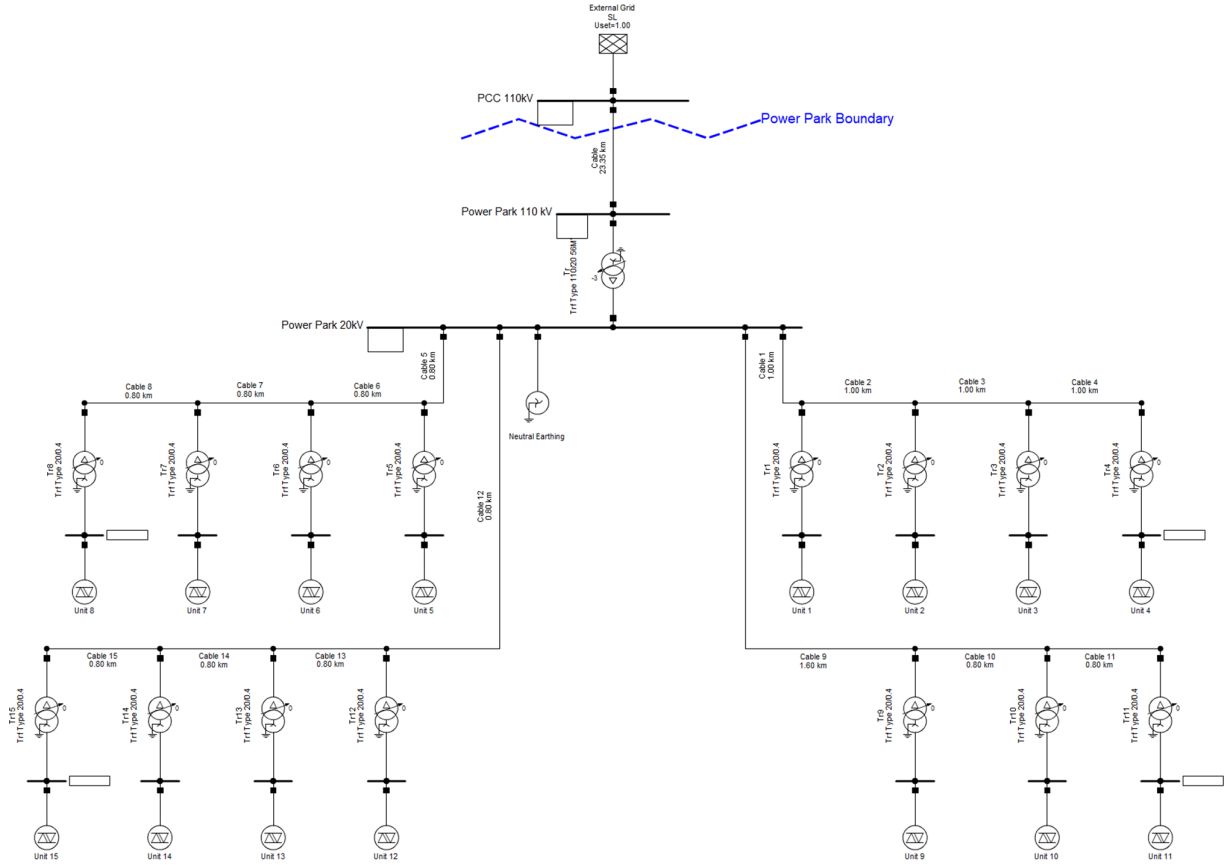
Case Studies

- Evaluate the impact of harmonic distortion on a renewable energy system connected to the utility grid.

- System model includes:
  - 15 inverter-based generating units with set up transformer
  - Interconnection transformer
  - Underground interconnection cable
  - Grid respresentation with background voltage distortion

- Scenarios analyzed:
  - Scenario 1 - **Background distortion only** (no inverter emission)
  - Scenario 2 -**Inverter emission only** (no background distortion considered)
  - Scenario 3 -Both Background and Inverter Emission

Case Studies



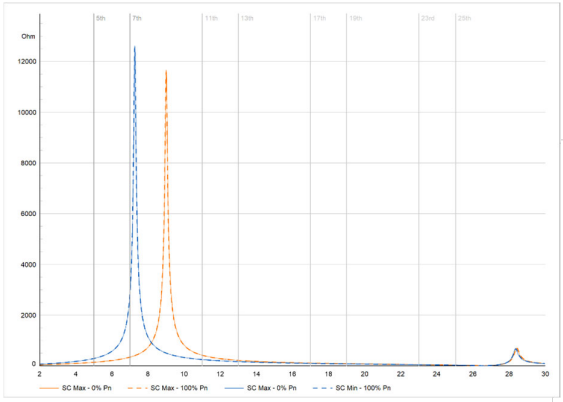
※Please note that this case study is only for demonstration purposes, and the voltage levels or other system parameters may differ from actual Japanese grid conditions.

Case Studies

- Frequency Sweep – **Resonance Risk Identification**
  - ✓Perform impedance scan at Point of Common Coupling (PCC)
  - ✓Use frequency sweep method to obtain system's f-Z profile
  - ✓Identify parallel or series resonance points
  - ✓Assess risk of harmonic amplification

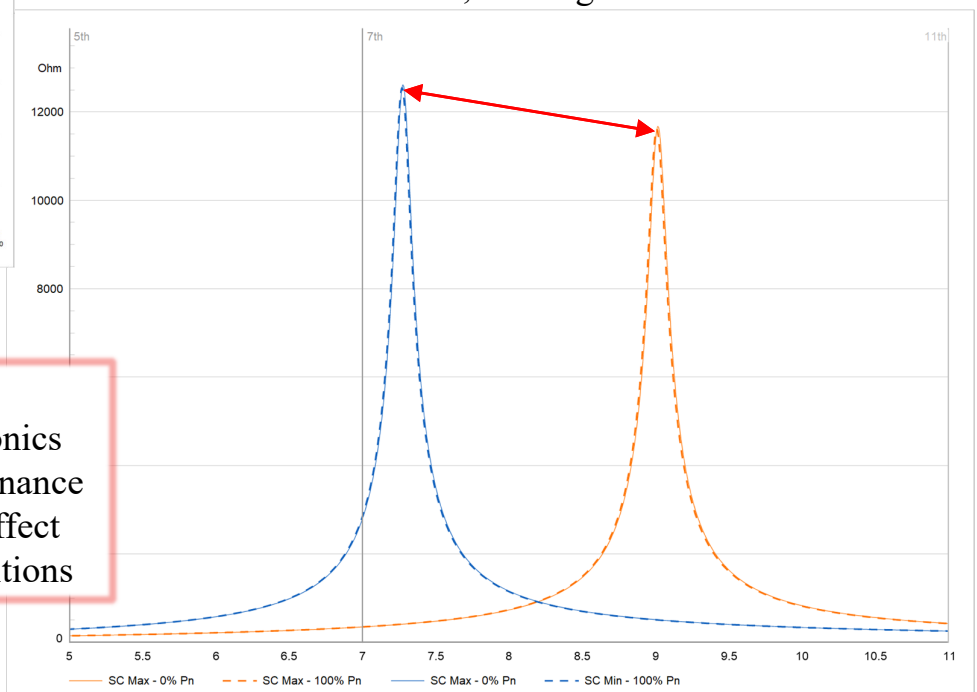
Case Studies

- Identify potential resonance frequencies under various short-circuit (SC) conditions and generation levels.



Case Analyzed:

- SC Max – 0%, 100% generation
- SC Min – 0%, 100% generation

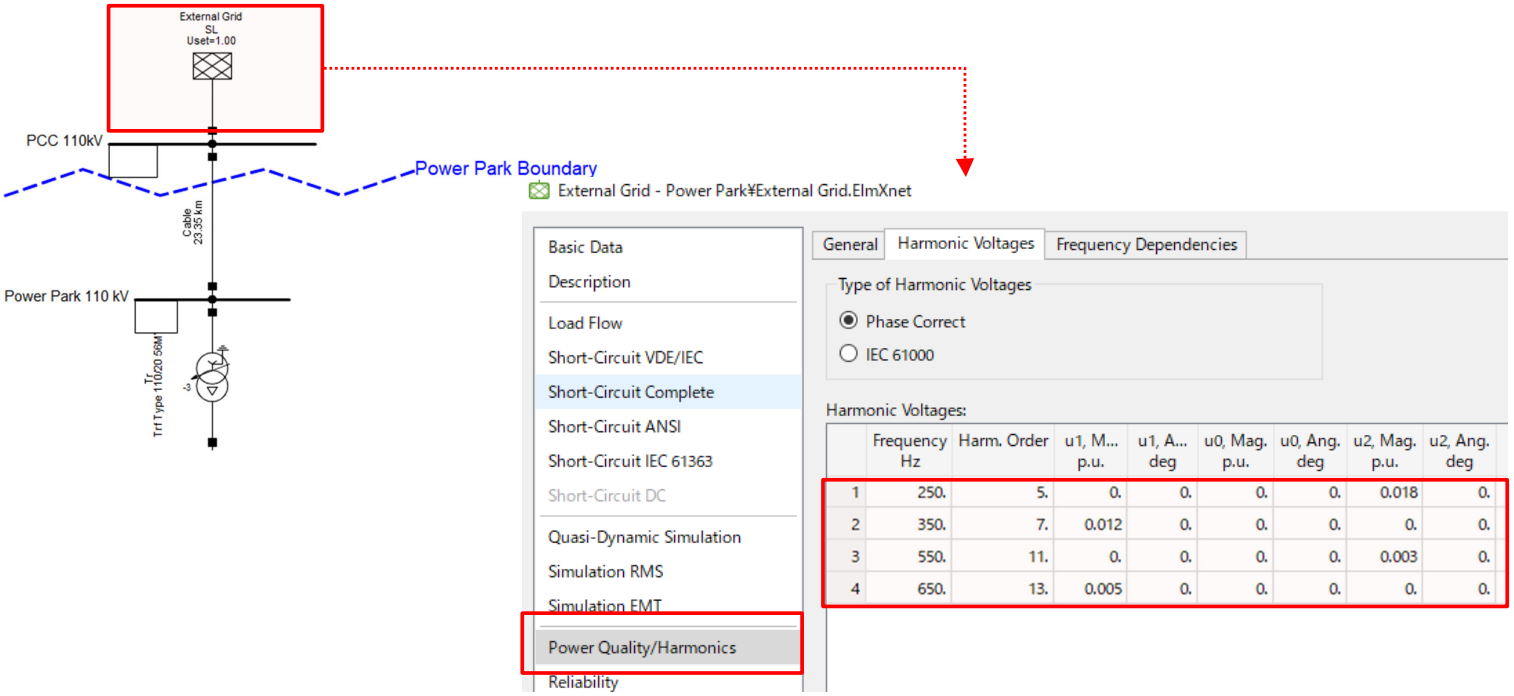


Key Observations:

- ✓ Resonance near 7th and 9th harmonics
- ✓ SC level strongly influences resonance
- ✓ Generation output has minimal effect
- ✓ Resonance varies with grid conditions

Case Studies : Scenario 1

- Harmonic Load Flow – **Background Harmonic Distortion** Injection
  - ✓Assess impact of existing grid harmonics (background distortion)
  - ✓No inverter harmonic emissions considered
  - ✓Focus on how background distortion affects voltage/current at PCC



	Frequency Hz	Harm. Order	u1, M... p.u.	u1, A... deg	u0, Mag. p.u.	u0, Ang. deg	u2, Mag. p.u.	u2, Ang. deg
1	250.	5.	0.	0.	0.	0.	0.018	0.
2	350.	7.	0.012	0.	0.	0.	0.	0.
3	550.	11.	0.	0.	0.	0.	0.003	0.
4	650.	13.	0.005	0.	0.	0.	0.	0.

Case Studies : Scenario 1

- **Note:** Consideration of Sequence Components of Harmonic injections

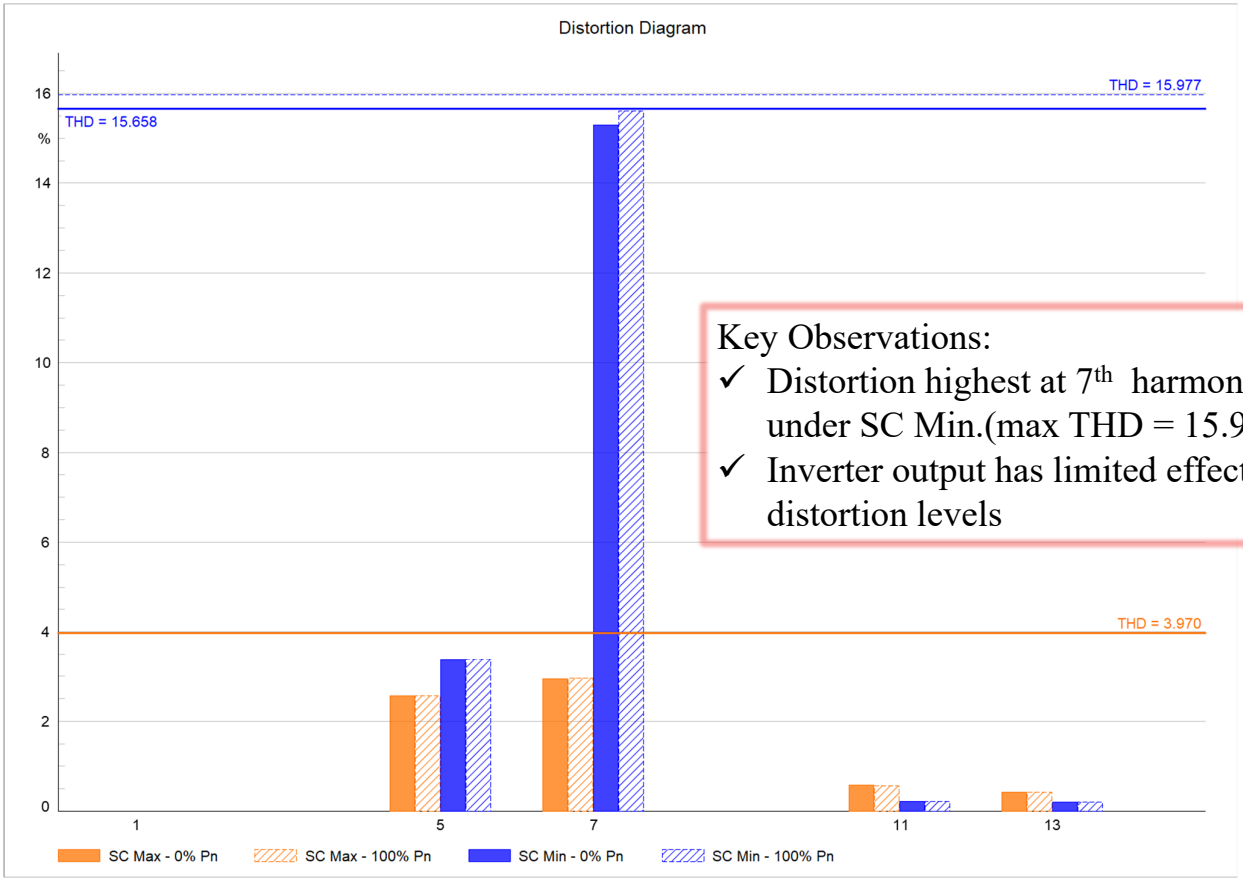
Harmonic Load Flow Command Setting	ElmVac/ElmXnet/ ElmSym Setting	Sequence Components of Harmonic Injections
Balanced	*Phase Correct*	• Positive (i.e. 4, 7, 10, ...), negative (i.e. 2, 5, 8, ...); • Non-integer harmonic orders (i.e. 5.5, 6.2, 8.35, ...) are considered in the positive sequence. • Triplen harmonics (i.e. 3, 6, 9, ...) are ignored (with warning).
	IEC 61000	• Positive, negative; • Triplen harmonics and non-integer harmonics are in the positive sequence.
Unbalanced	*Phase Correct*	• Positive, negative, zero sequence; • Non-integer harmonics are considered.
	IEC 61000	• As for balanced harmonic load flow.

Table 35.4.4: Consideration of Sequence Components of Harmonic Injections for AC Voltage Source, External Grid and Synchronous Machine

Source: DigSILENT *PowerFactory 2023*, User Manual (Page 1038)

Case Studies : Scenario 1

- Distortion results under four cases (SC Max/Min, 0%/100% gen)

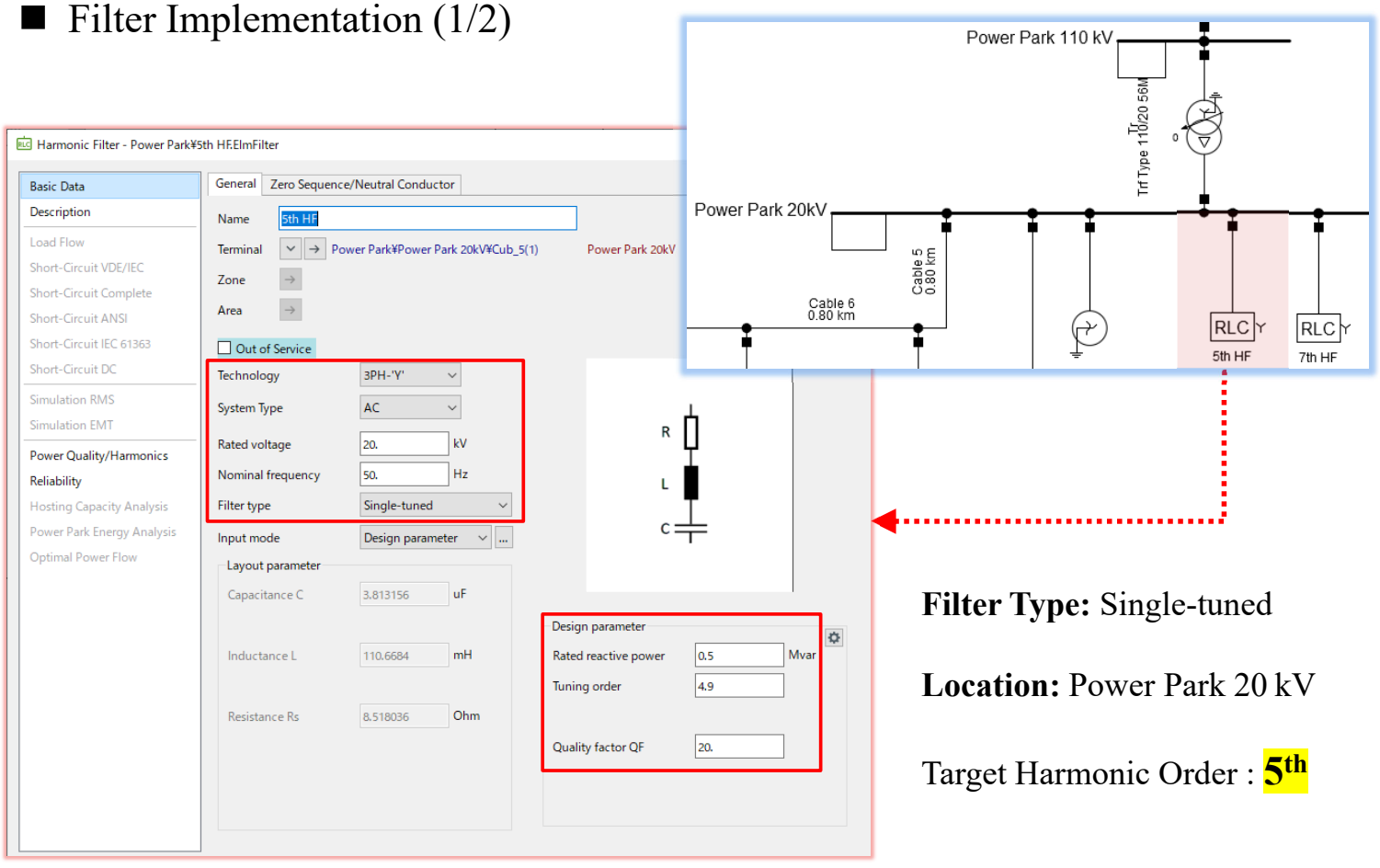


Key Observations:

- ✓ Distortion highest at 7th harmonic under SC Min.(max THD = 15.977%)
- ✓ Inverter output has limited effect on distortion levels

Case Studies : Scenario 1

- Filter Implementation (1/2)



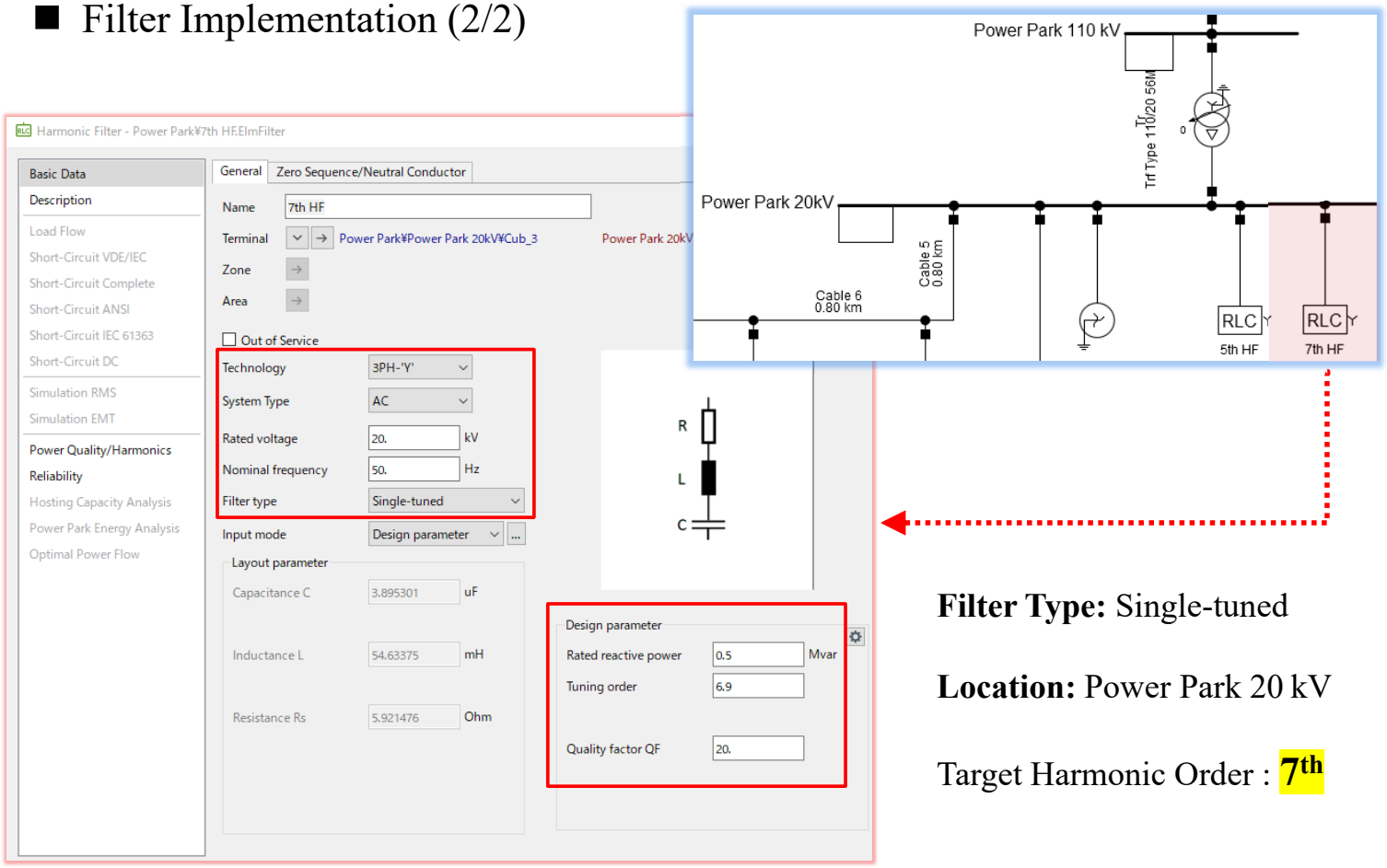
Filter Type: Single-tuned

Location: Power Park 20 kV

Target Harmonic Order : **5th**

Case Studies : Scenario 1

■ Filter Implementation (2/2)



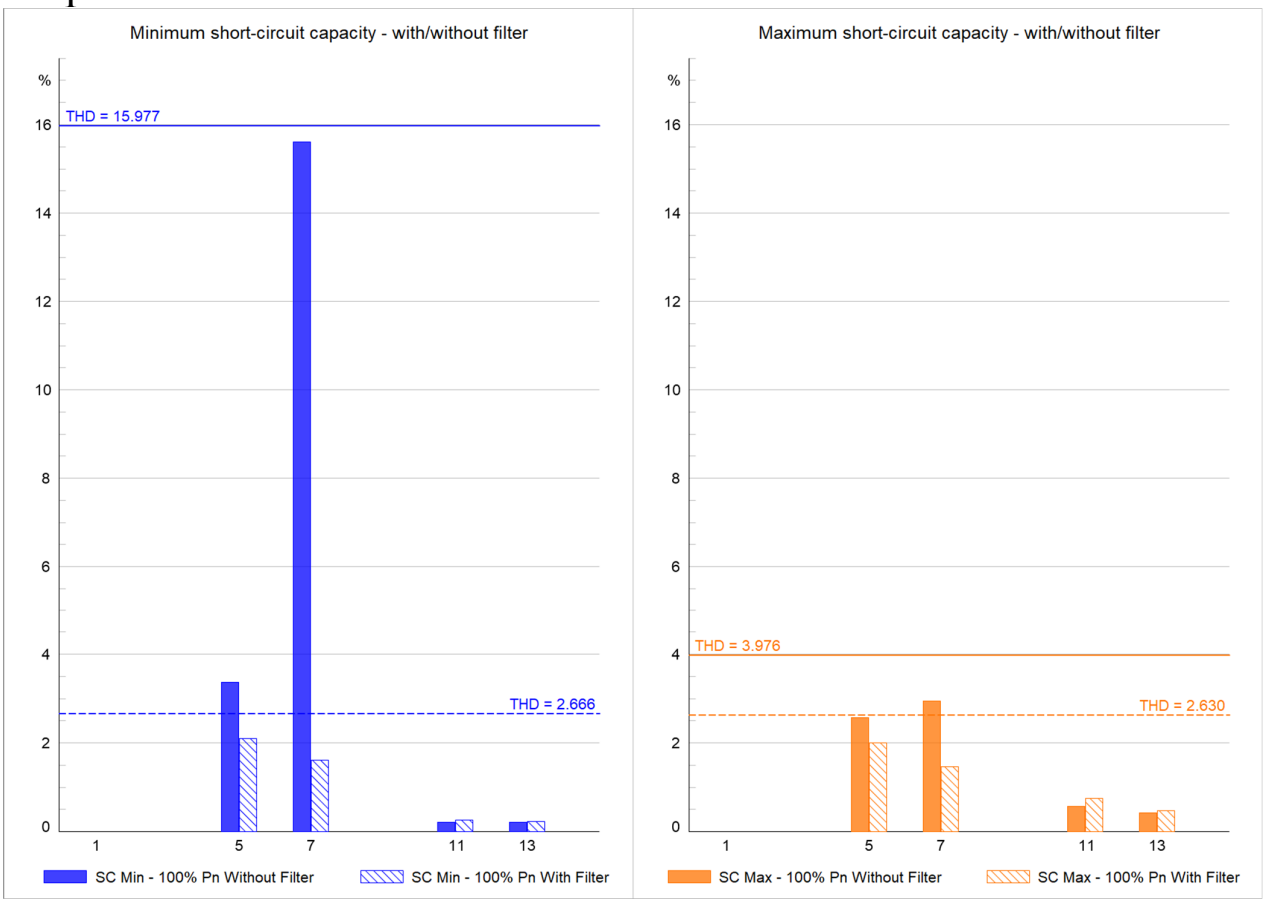
Filter Type: Single-tuned

Location: Power Park 20 kV

Target Harmonic Order : **7th**

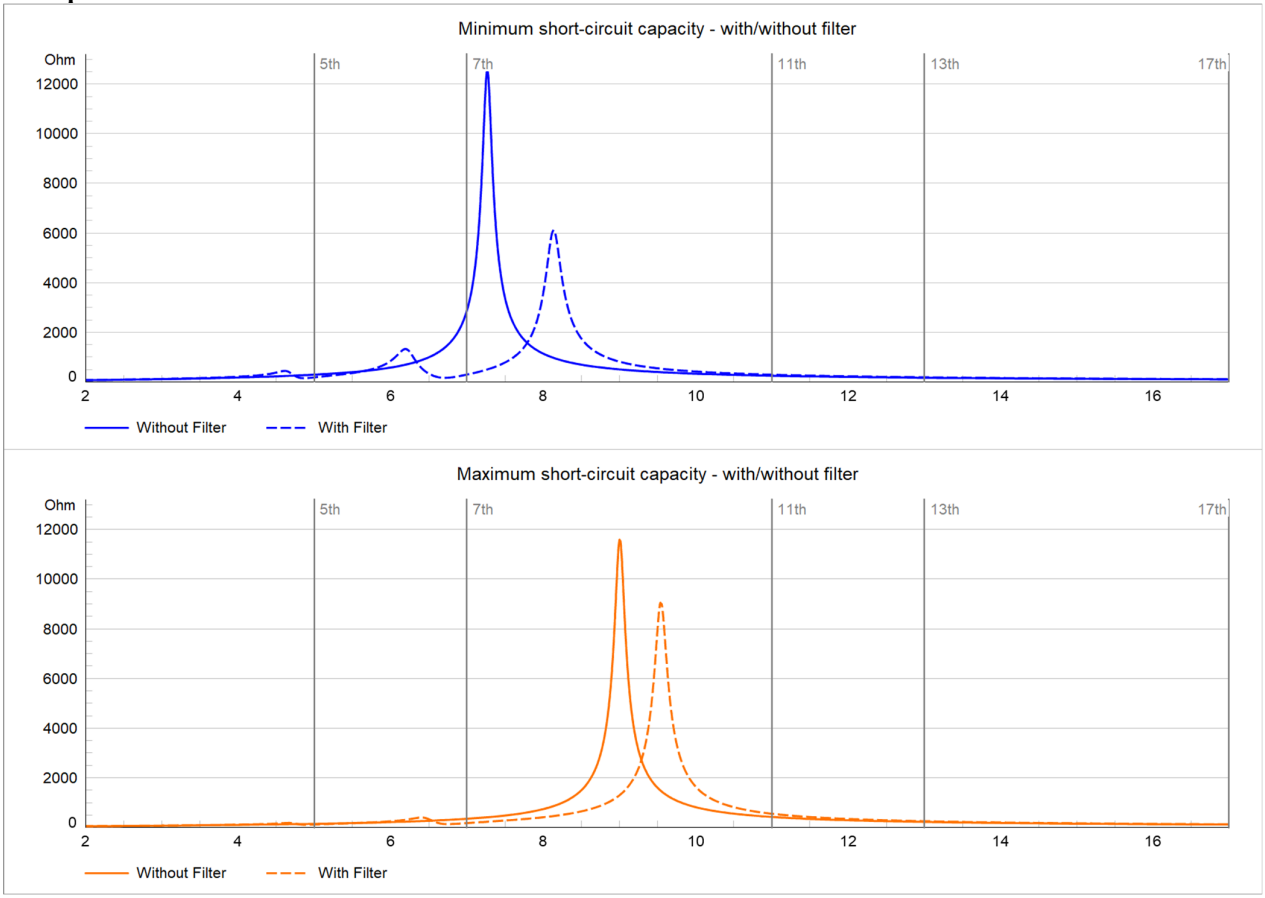
Case Studies : Scenario 1

■ Comparison – With vs Without Filter



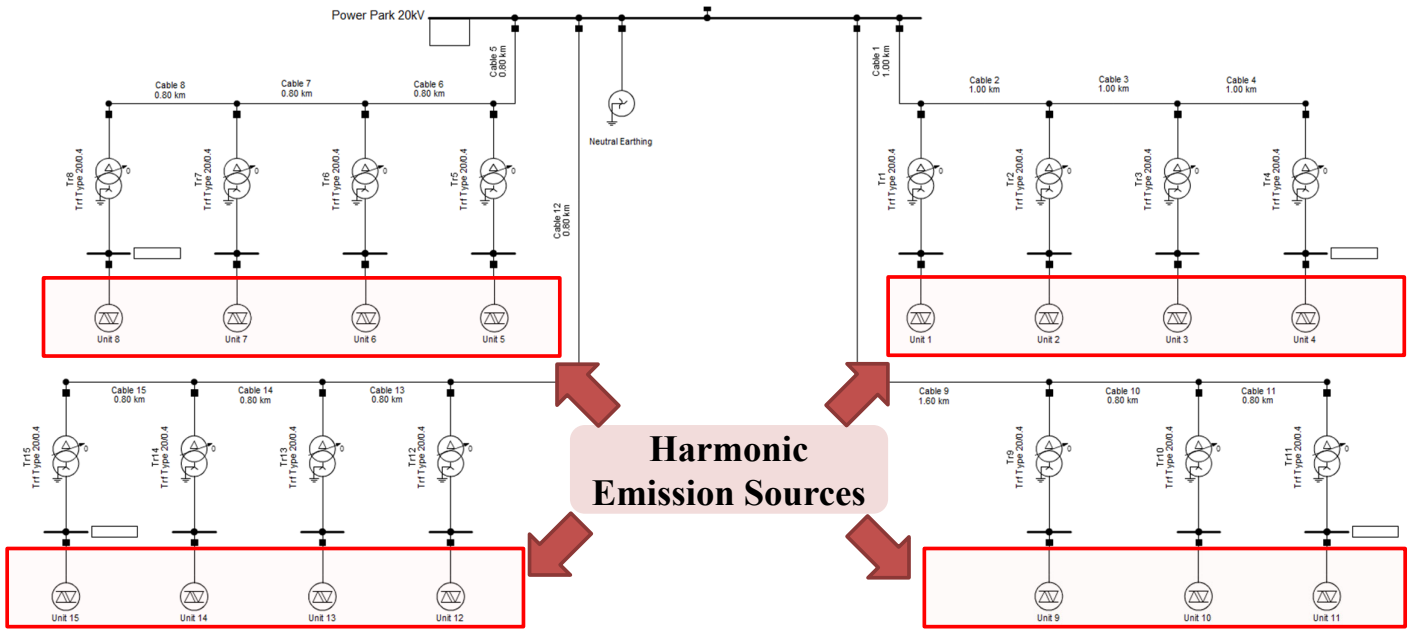
Case Studies : Scenario 1

- Comparison – With vs Without Filter



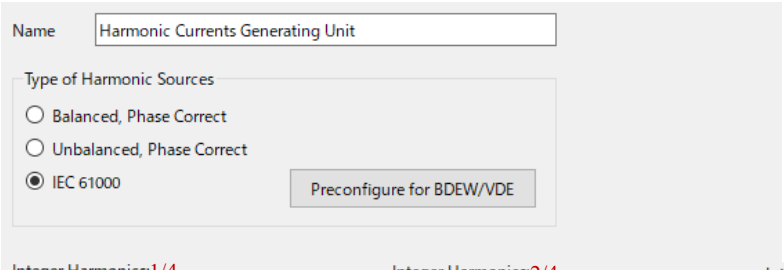
Case Studies : Scenario 2

- Harmonic Load Flow – **Harmonic Emissions from Inverter-based Equipment**
  - ✓Focuses on harmonic emissions from inverter-based equipment only
  - ✓Background distortion from the power system is not considered



Case Studies : Scenario 2

- Harmonic Load Flow – **Harmonic Emissions from Inverter-based Equipment (Setup Data)**



Harmonic Current Data – 2nd to 50th Harmonic

Data Format : Harmonic current magnitude as percentage of fundamental (I_h/I %)

Integer Harmonics:1/4

	I_h/I %
f/fn=2	0.6639441
f/fn=3	0.5579
f/fn=4	0.1560498
f/fn=5	1.272409
f/fn=6	0.2598106
f/fn=7	0.6207742
f/fn=8	0.1425225
f/fn=9	0.1115214
f/fn=10	0.1765604
f/fn=11	0.2866716
f/fn=12	0.1119317
f/fn=13	0.1189279
f/fn=14	0.04336836

Integer Harmonics:2/4

	I_h/I %
f/fn=15	0.03589631
f/fn=16	0.04556151
f/fn=17	0.04887755
f/fn=18	0.05784359
f/fn=19	0.08442513
f/fn=20	0.02023367
f/fn=21	0.03000442
f/fn=22	0.06758062
f/fn=23	0.05283785
f/fn=24	0.09268989
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Integer Harmonics:3/4

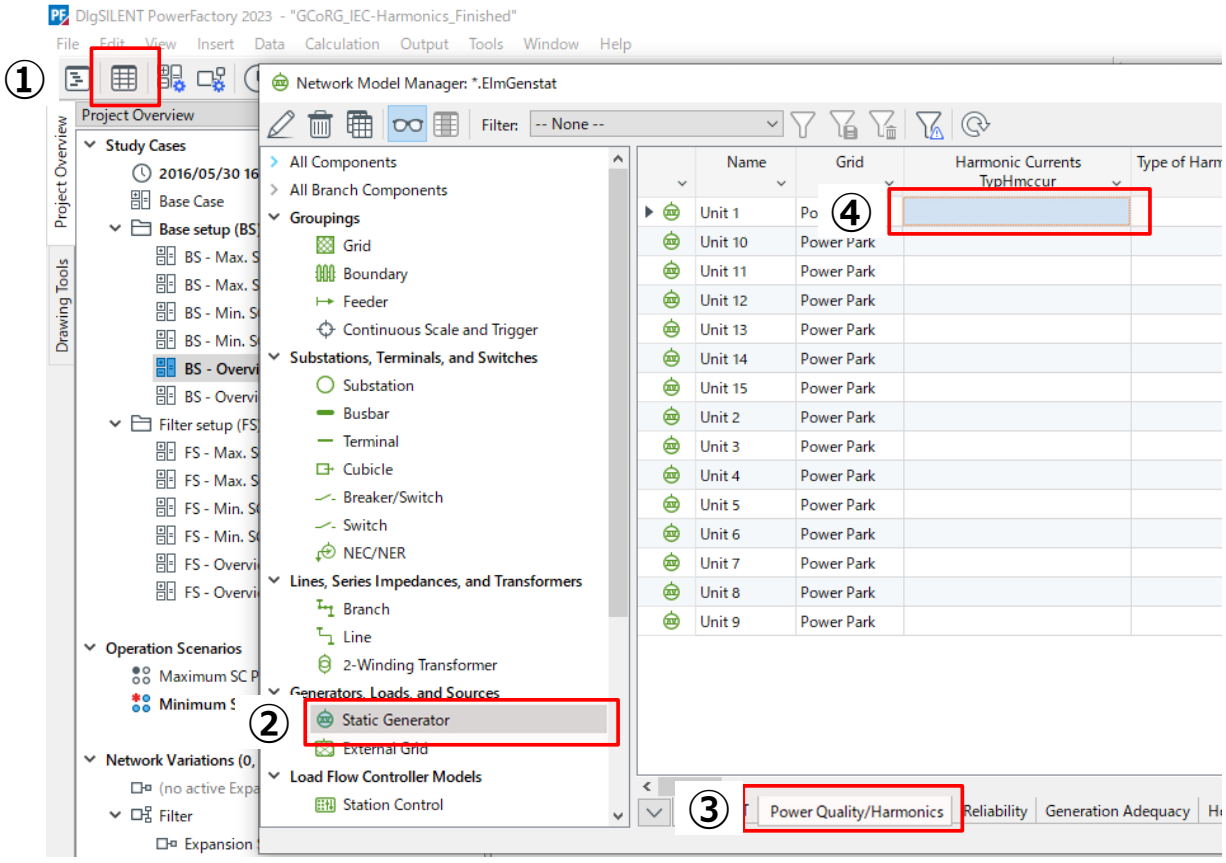
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f/fn=31	0.02929496
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f/fn=34	0.04827873
f/fn=35	0.03933864
f/fn=36	0.03095356
f/fn=37	0.0288692
f/fn=38	0.02931101
f/fn=39	0.02956629
f/fn=40	0.03626185

Integer Harmonics:4/4

	I_h/I %
f/fn=38	0.02931101
f/fn=39	0.02956629
f/fn=40	0.03626185
f/fn=41	0.04296618
f/fn=42	0.06049277
f/fn=43	0.06135276
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f/fn=50	0.1583403

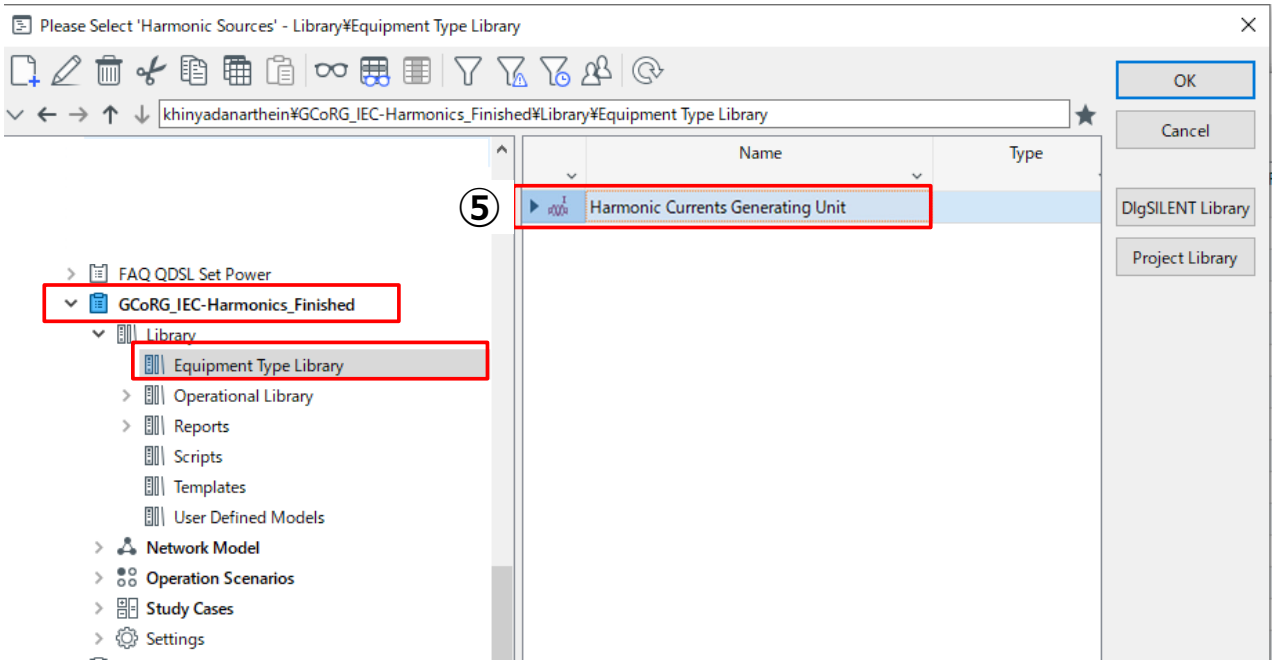
Case Studies : Scenario 2

- Setting harmonic current injection type in static generator models



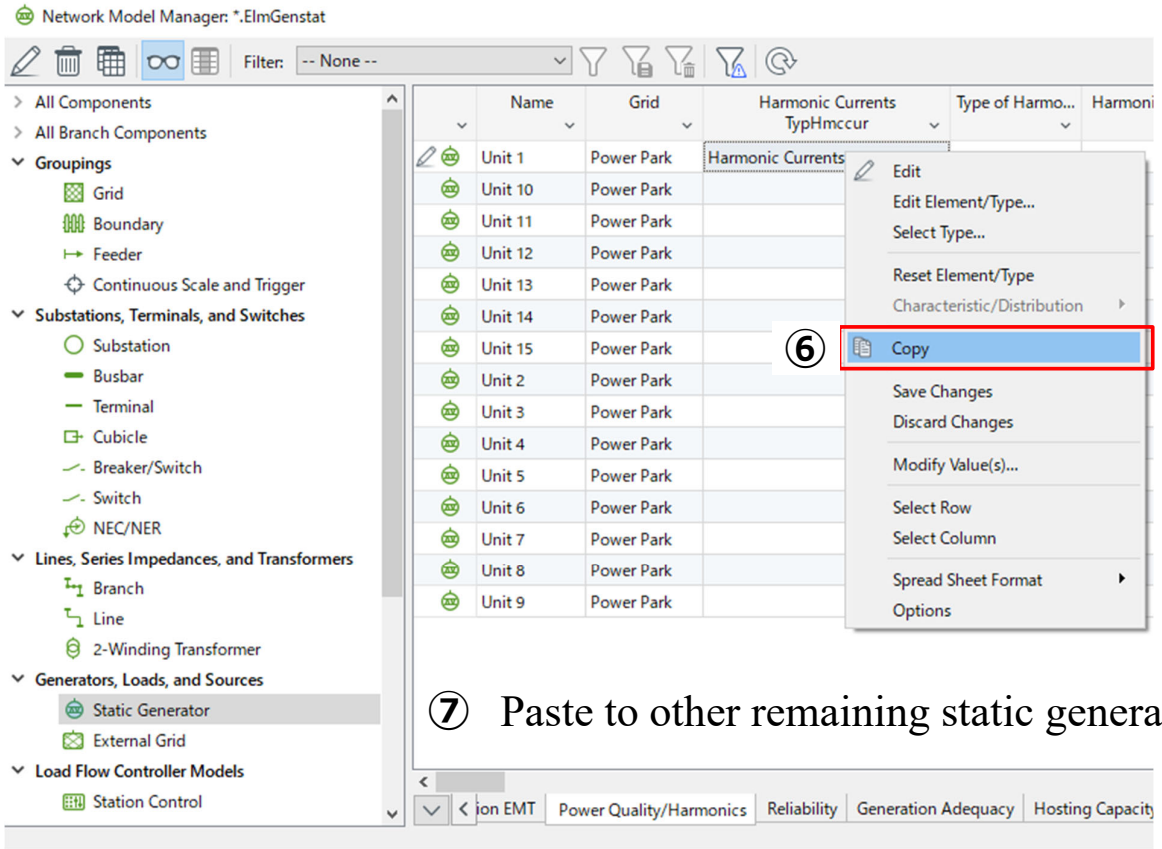
Case Studies : Scenario 2

■ Setting harmonic current injection type in static generator models



Case Studies : Scenario 2

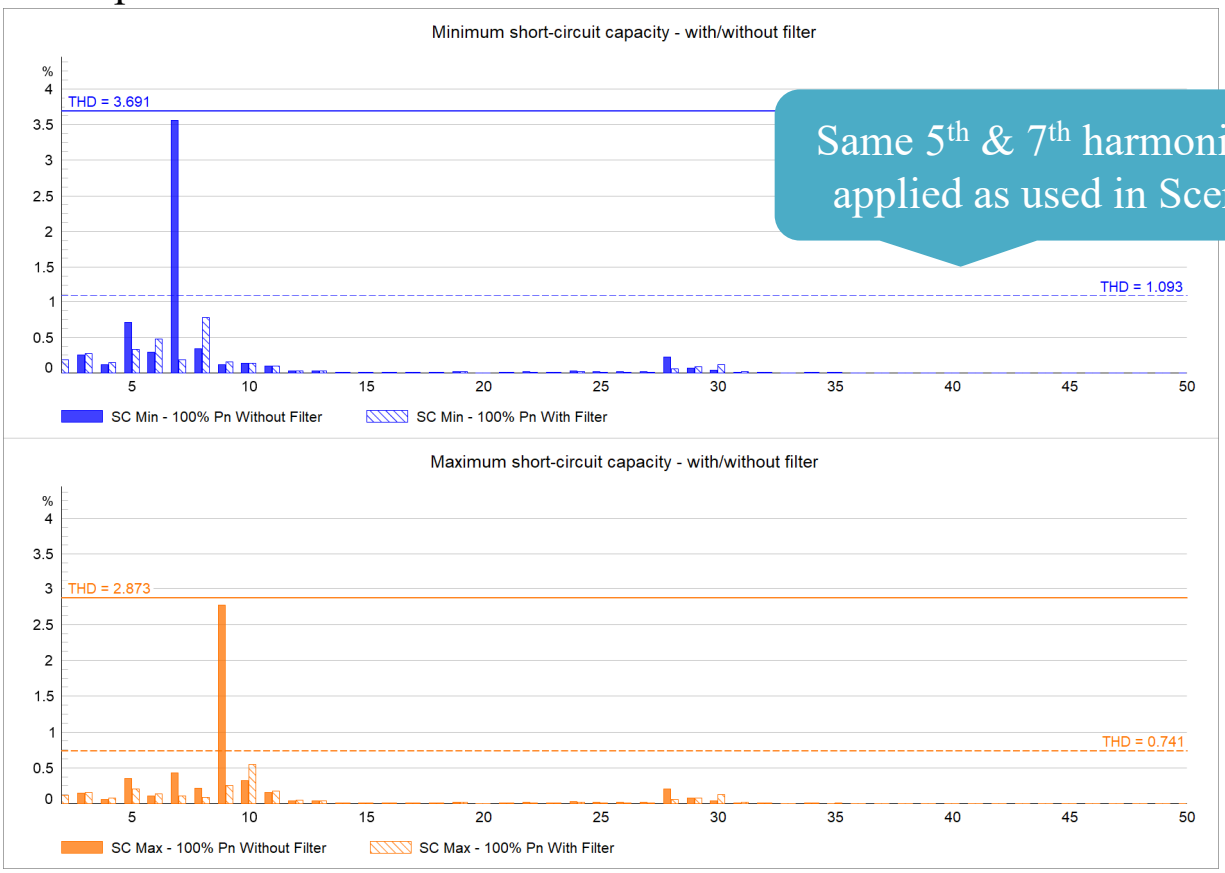
■ Setting harmonic current injection type in static generator models



⑦ Paste to other remaining static generators

Case Studies : Scenario 2

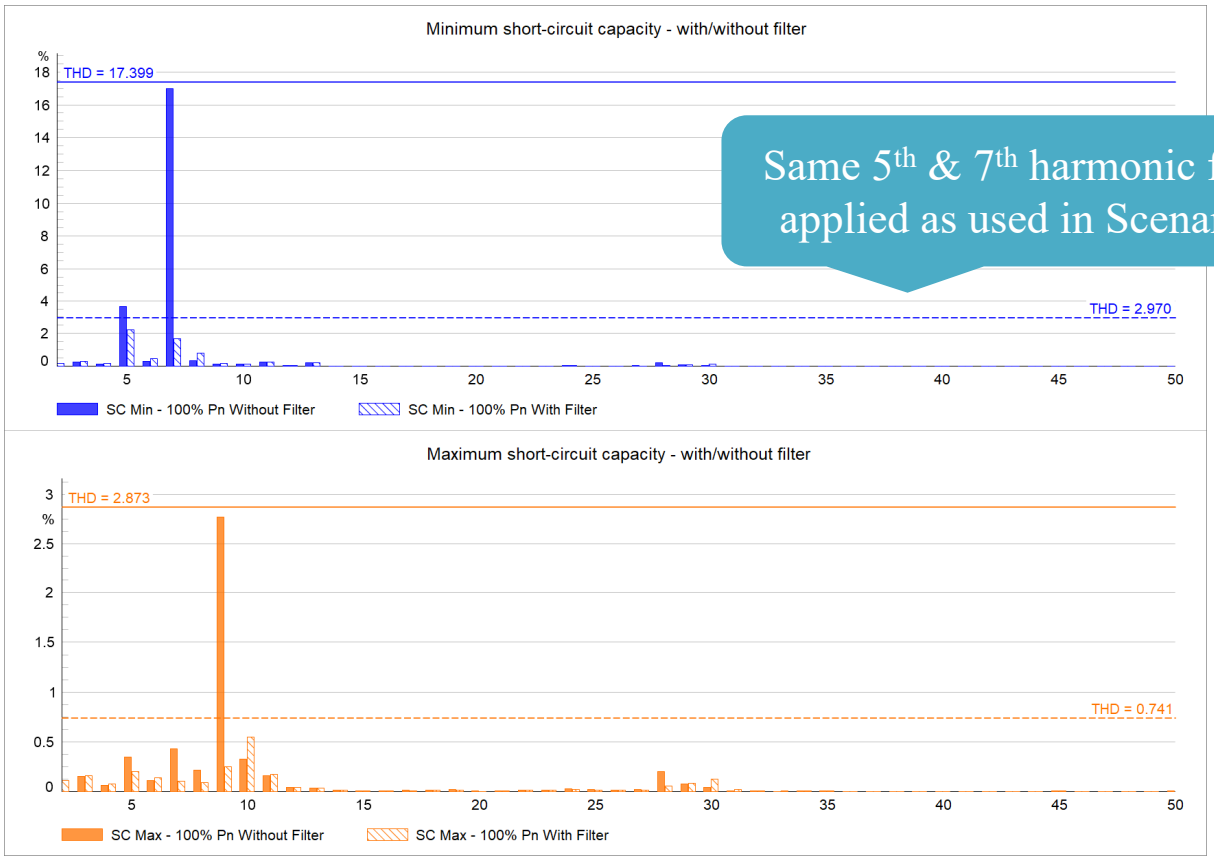
- Comparison – With vs Without Filter



Same 5th & 7th harmonic filters applied as used in Scenario 1

Case Studies : Scenario 3

- Comparison – With vs Without Filter



Same 5th & 7th harmonic filters applied as used in Scenario 1

8. Challenges & Considerations

Challenges & Considerations

- Limited Manufacturer Data
  - Detailed harmonic emission profiles from PCS manufacturers are often unavailable or insufficient.
- Unknown Utility Grid Frequency Characteristics
  - The Frequency-dependent grid impedance is rarely provided, making resonance analysis difficult.
- Modeling Complexity
  - Accurate harmonic analysis requires detailed grid and equipment models, including frequency-dependent behavior of cables, transformers, and filters.
  - Limited data can lead to uncertain simulation results.
- Changing Grid Conditions
  - Grid reconfiguration (e.g., line switching, tap changes, SCC variations) affects harmonic behavior.
  - Harmonic performance is **not static** and must be evaluated under multiple scenarios.

Challenges & Considerations

- Resonance Risk
  - When multiple PCS-based generation systems connect to the same grid, the overall frequency-dependent impedance (f-Z characteristic) can change, shifting resonance points to lower frequencies.

- Filter Design and Coordination
  - Proper design and placement of harmonic filters is necessary to mitigate resonance and distortion.
  - Filter designed for individual wind farms (WFs) may become ineffective or even counterproductive when multiple WFs are interconnected.
  - Coordination is required to prevent interaction between multiple filters.

- Validation and Measurement
  - Post-installation measurements are essential to validate analysis results and ensure compliance.
  - Continuous monitoring may be required for large-scale plants.

Presentation Material 2- 6

Activity 2-2-2-1 Simulation Methods for the Impact of EVs on the Electric Power Distribution System (Voltage Profile Analysis)

Simulation Methods for the Impact of EVs on the Electric Power Distribution System (Voltage Profile Analysis)

Activity 2-2-2-1

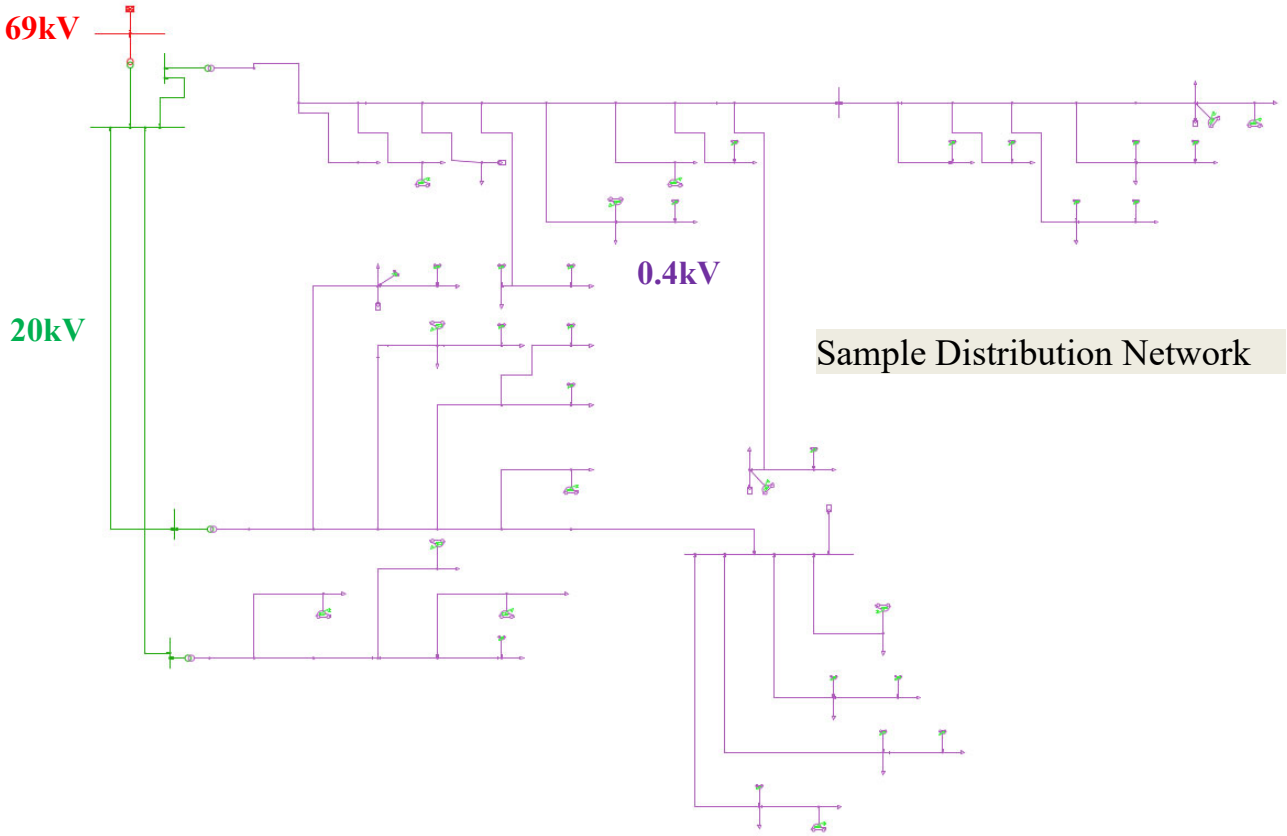
JICA Expert Team

Japan International Cooperation Agency
Tokyo Electric Power Services Company, Ltd.

Agenda in this presentation

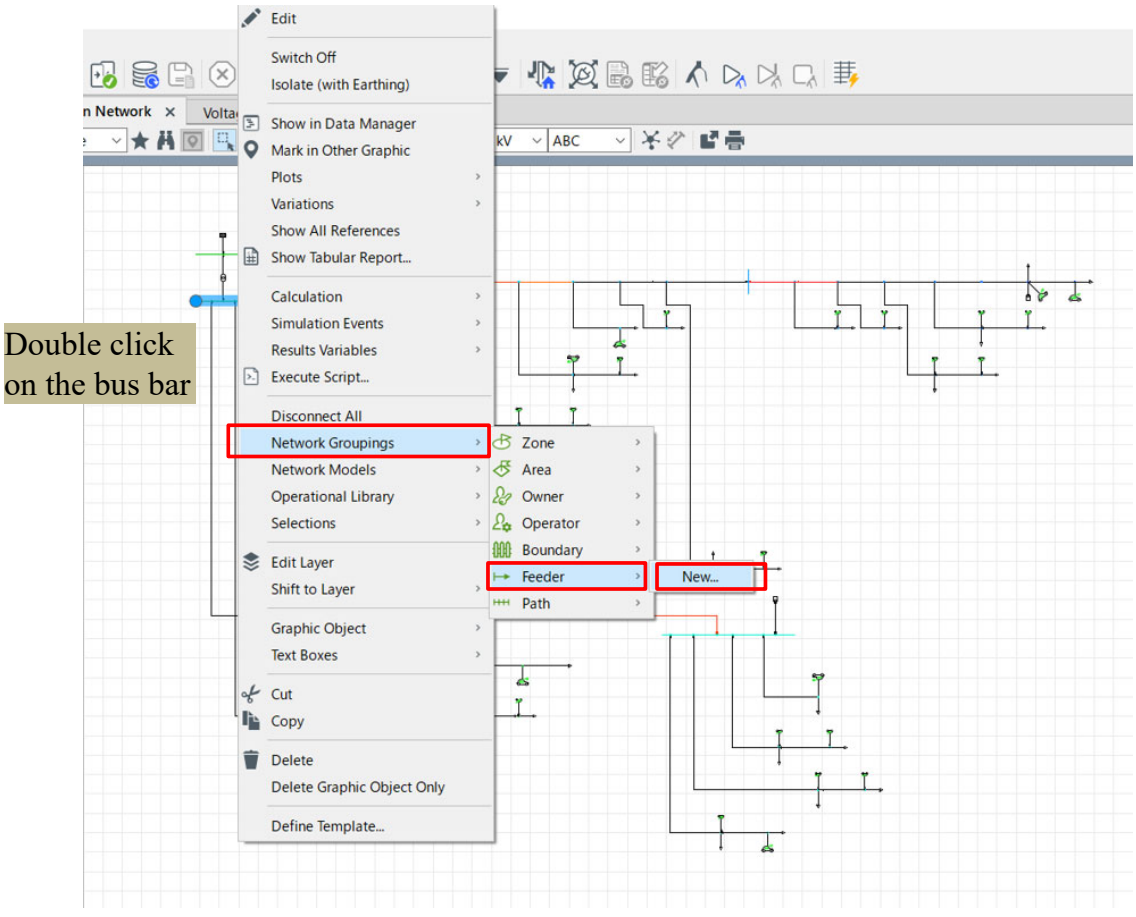
WG	Activities		Activities	JICA expert	STEG	Time schedule
2	**2-1**		**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2	2-1-1		Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2	2-1-2		Introduction of case studies in Japan	✓		2nd
2	**2-2**		**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2	2-2-1		Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2	2-2-2		Lecture on simulation methods for the impact of EVs on the electric power distribution system(Coincidence Factor)	✓		3rd
2	2-2-2-1	A	Lecture on simulation methods for the impact of EVs on the electric power distribution system(Harmonic, voltage drop)			4th
2	2-2-3		Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2	2-2-4		Discussion on the issues and countermeasures	✓	✓	3rd
2	2-2-5		Create the conclusion report	✓	✓	6th-
2	**2-3**		**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2	2-3-1		Share the report of EV penetration scenario in Tunisia		✓	1st
2	2-3-2		Create/Assume a scenario of EV penetration	(✓)	✓	1st - 3rd
2	2-3-3		Lecture on the methodology for electricity demand forecast of EV in Japan	✓		4th
2	2-3-4		Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2	2-3-5		Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2	2-3-6		Report the comments to STEG	✓		5th
2	2-3-7		Discussion on the comments	✓	✓	5th
2	2-3-8		Improve the methodology	✓	✓	5th-

Analysis of Voltage Profile in EV Distribution Network

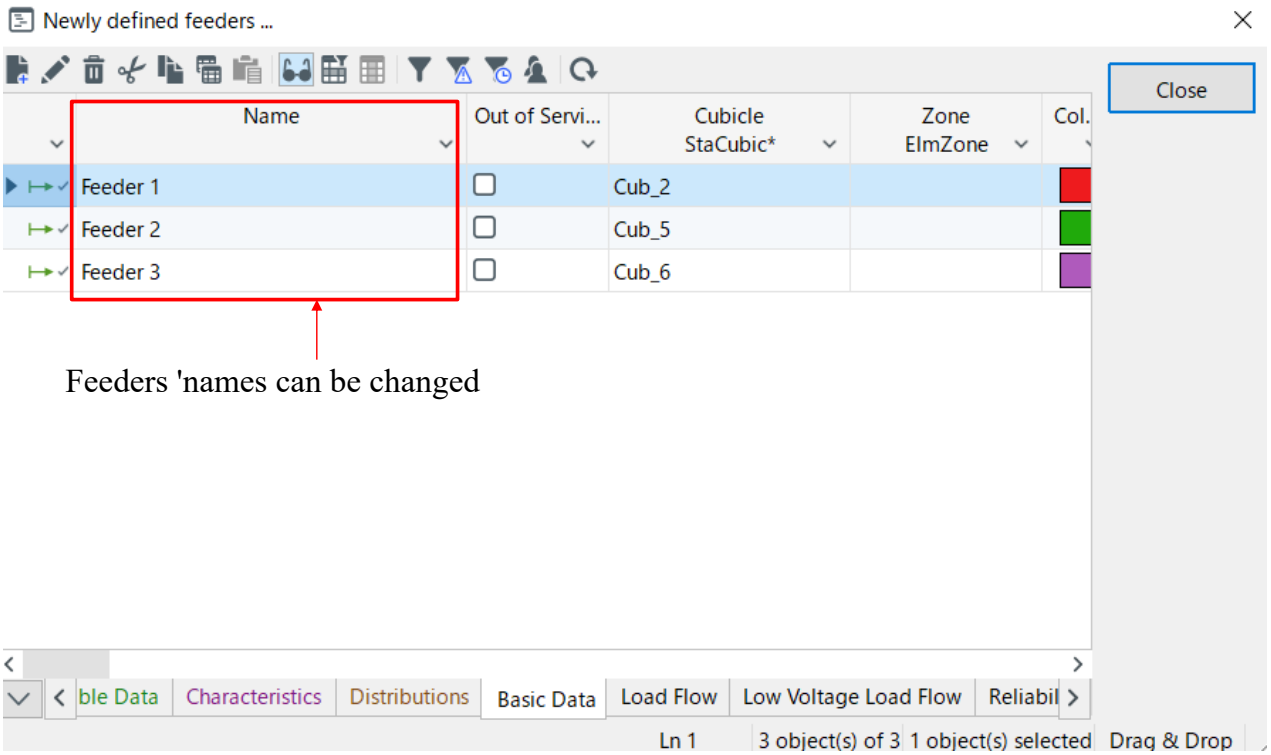


Sample Distribution Network

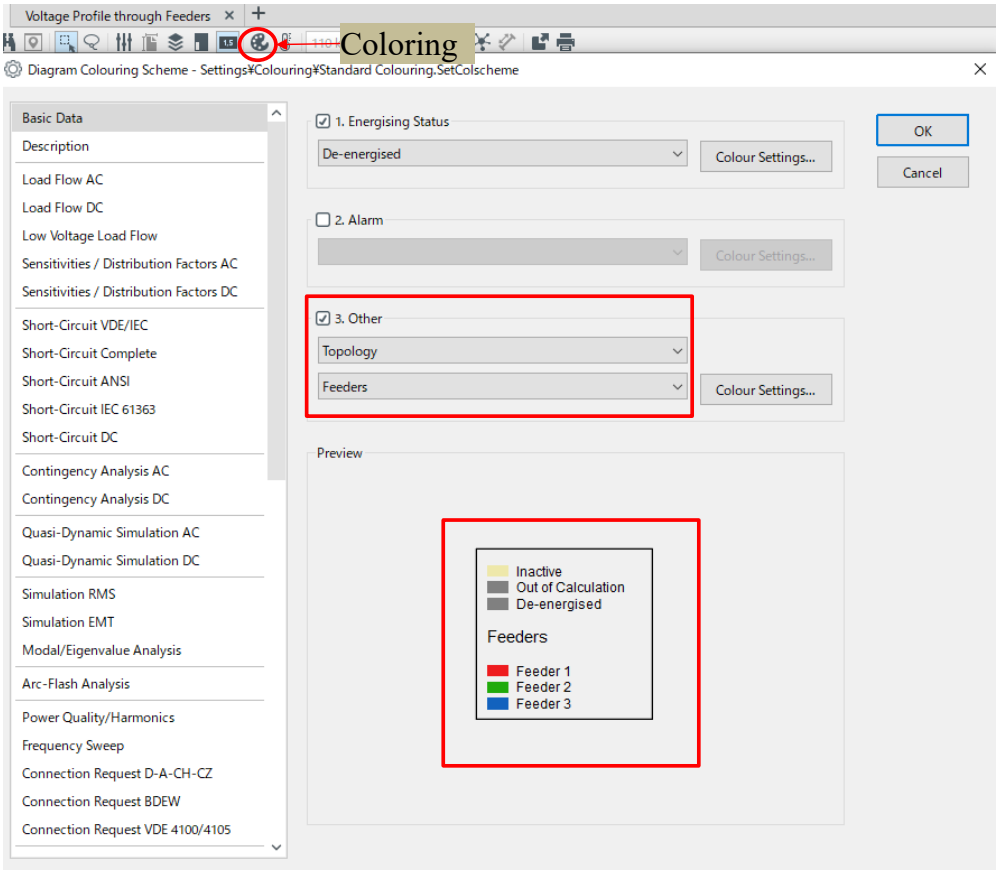
How to Set Feeders in Distribution Network



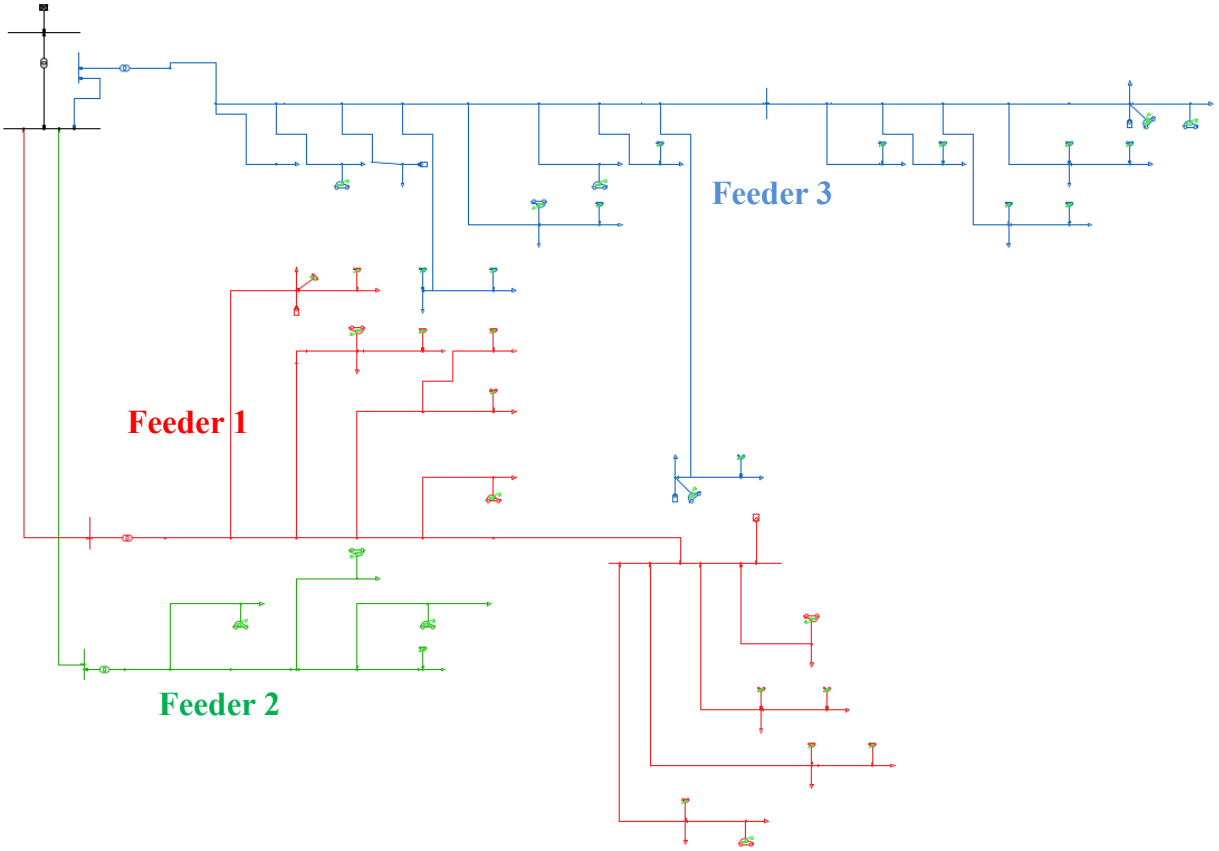
How to Set Feeders in Distribution Network



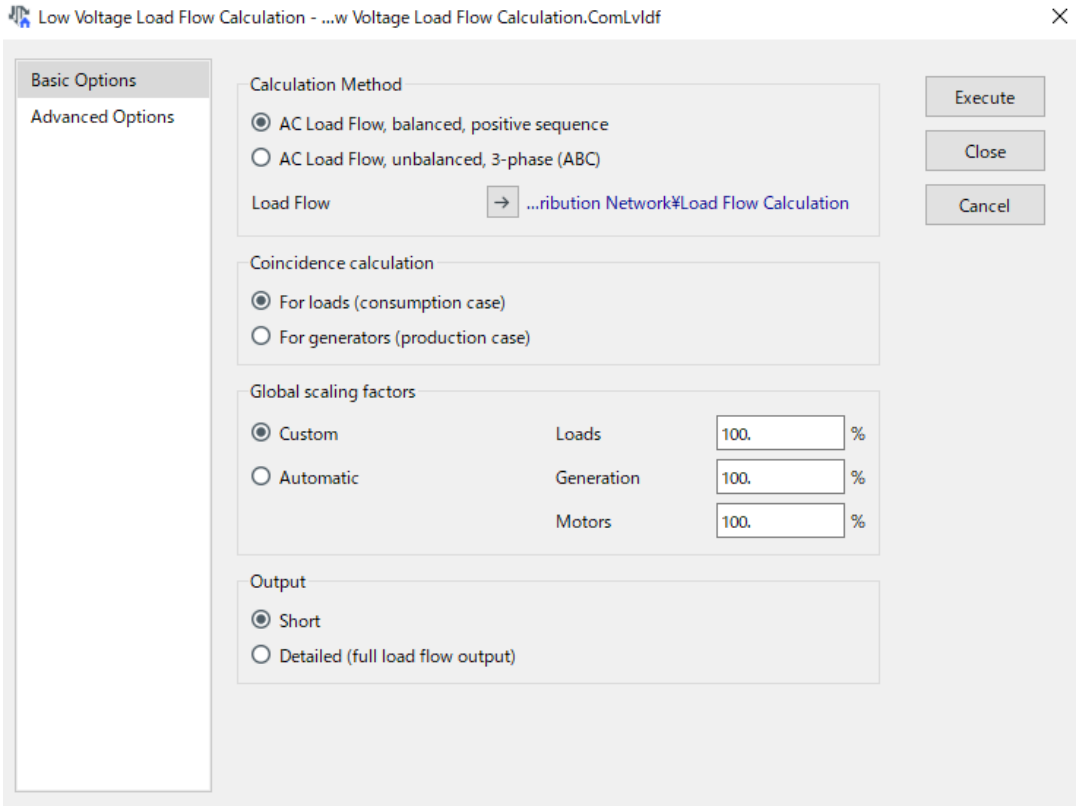
How to Set Feeders in Distribution Network



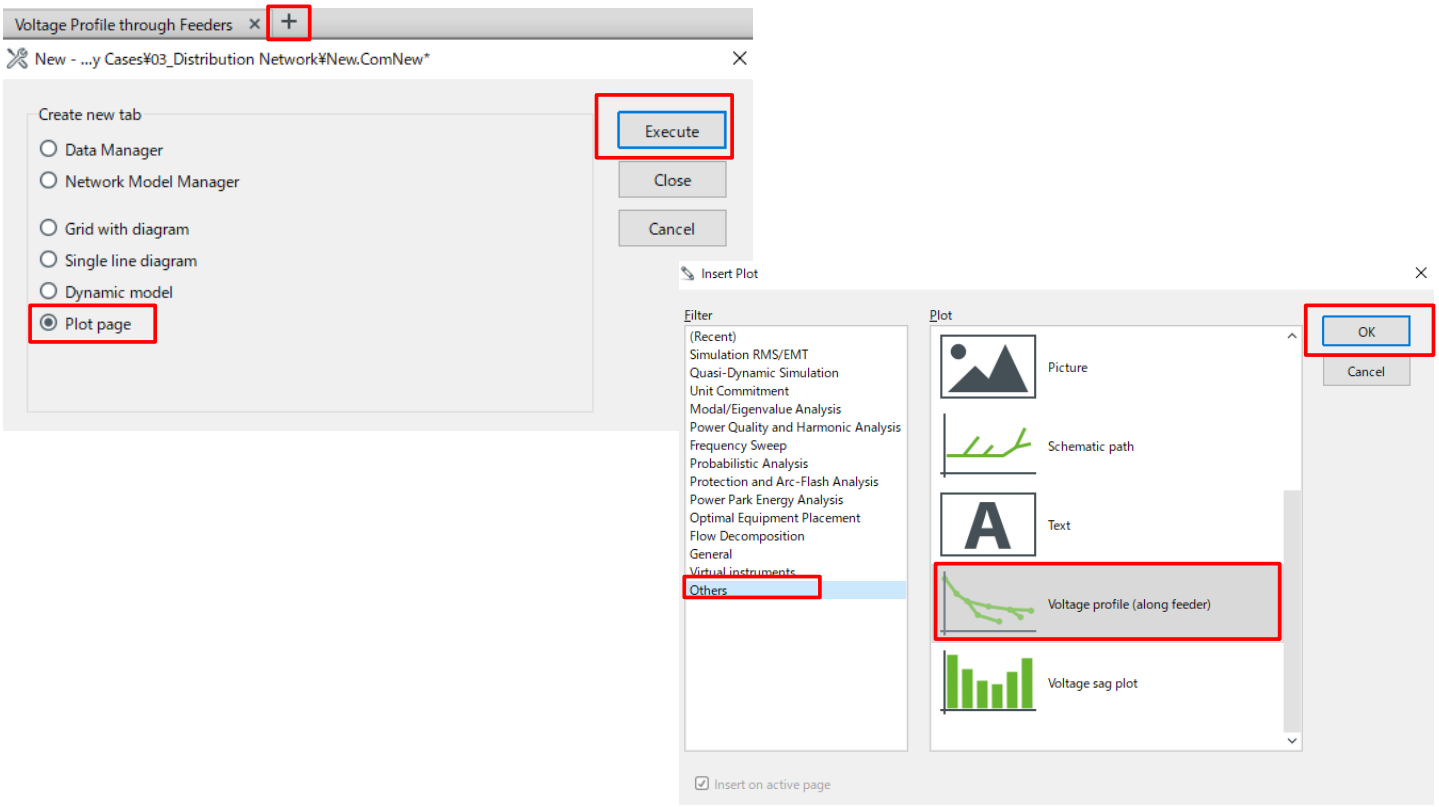
How to Set Feeders in Distribution Network



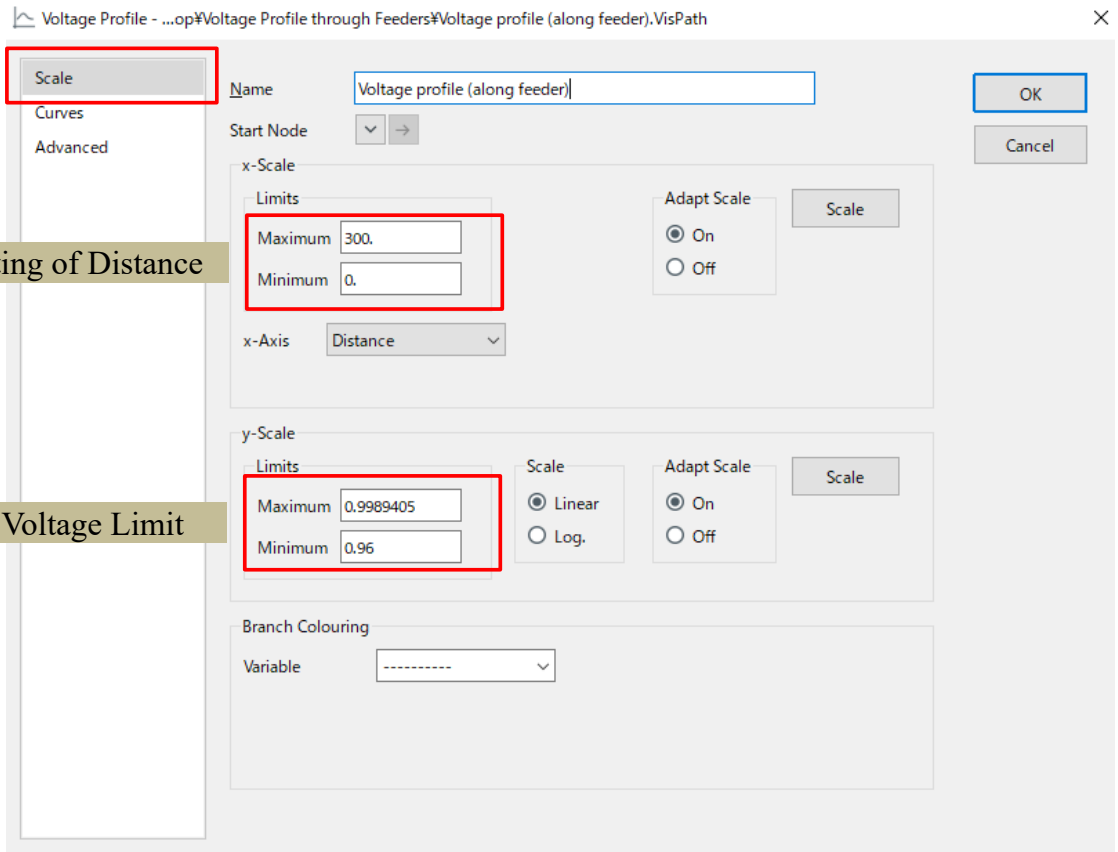
Execute Low Voltage Load Flow Calculation



Creating Plot for Voltage Profile (Along Feeder)



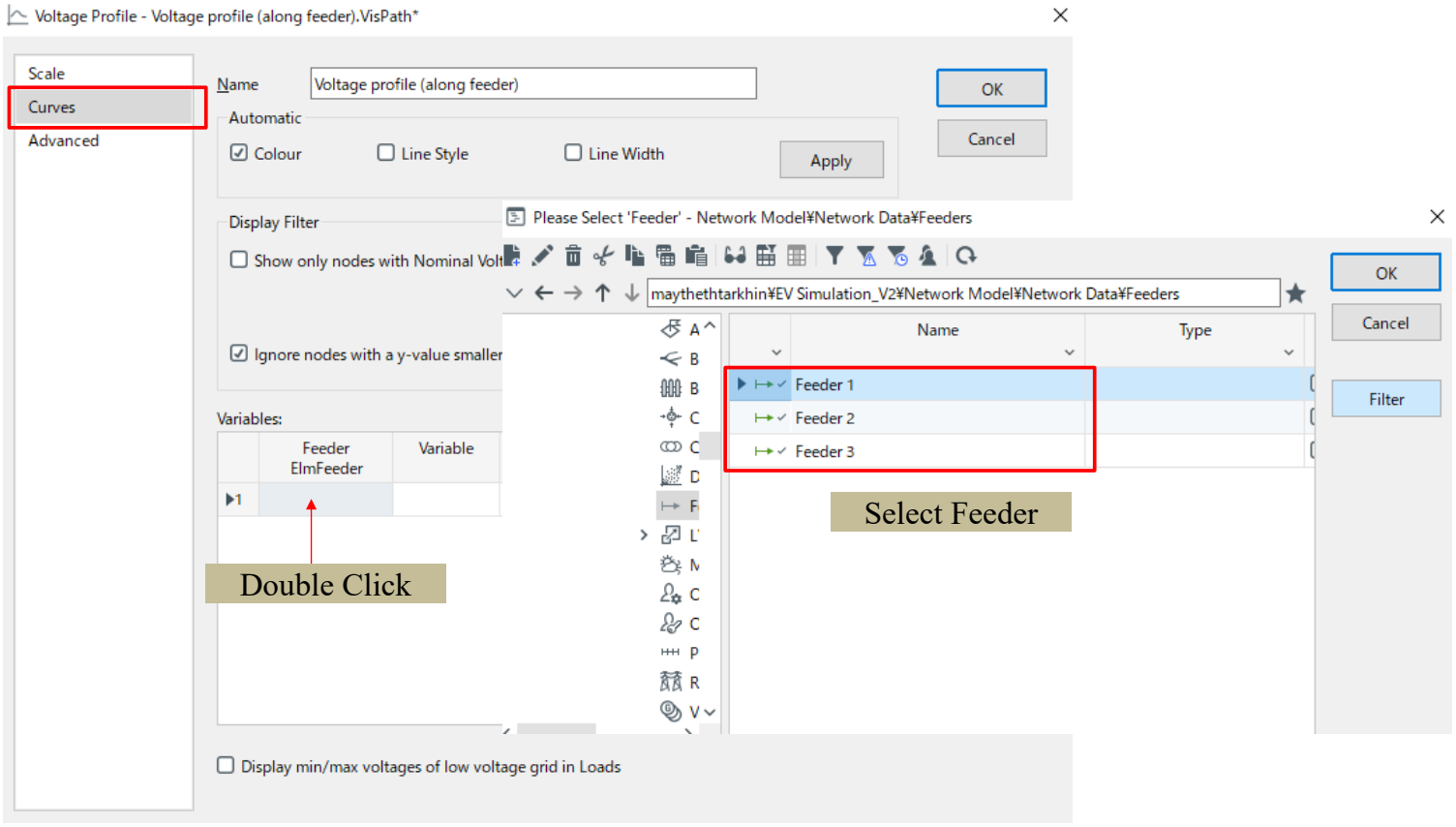
Creating Plot for Voltage Profile (Along Feeder)



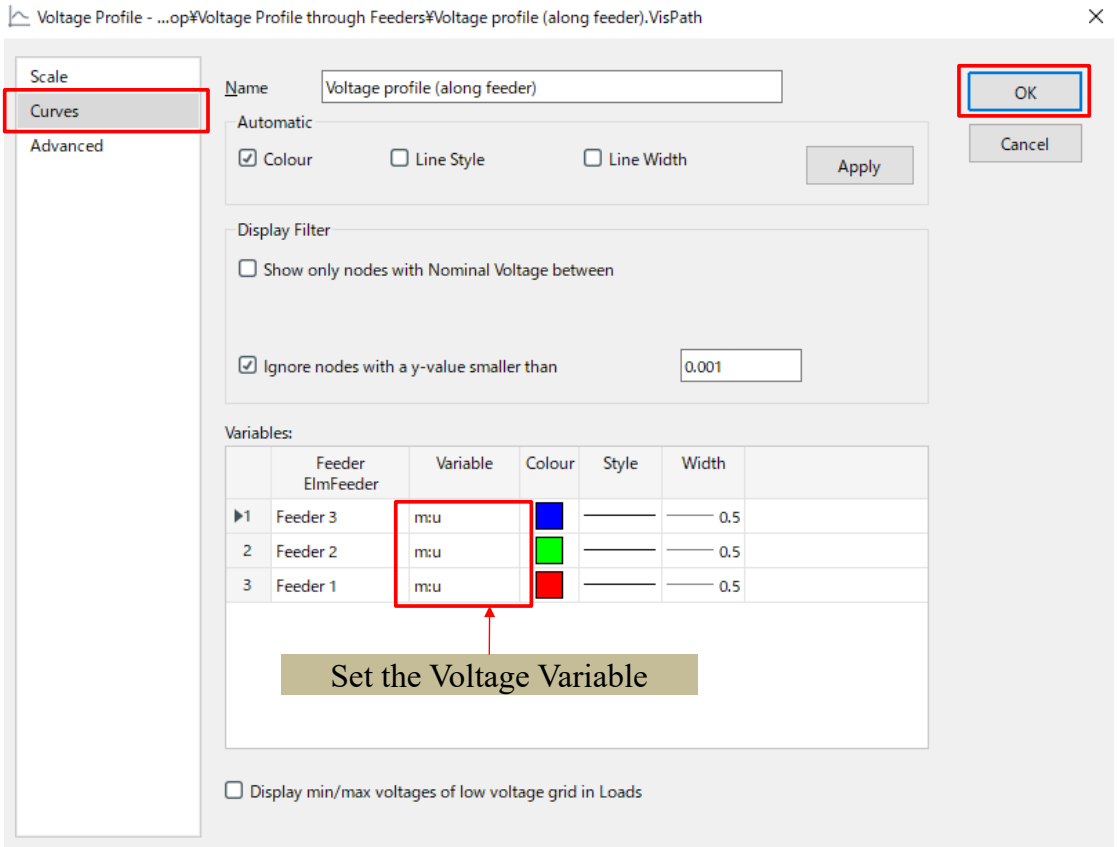
Setting of Distance

Setting of Voltage Limit

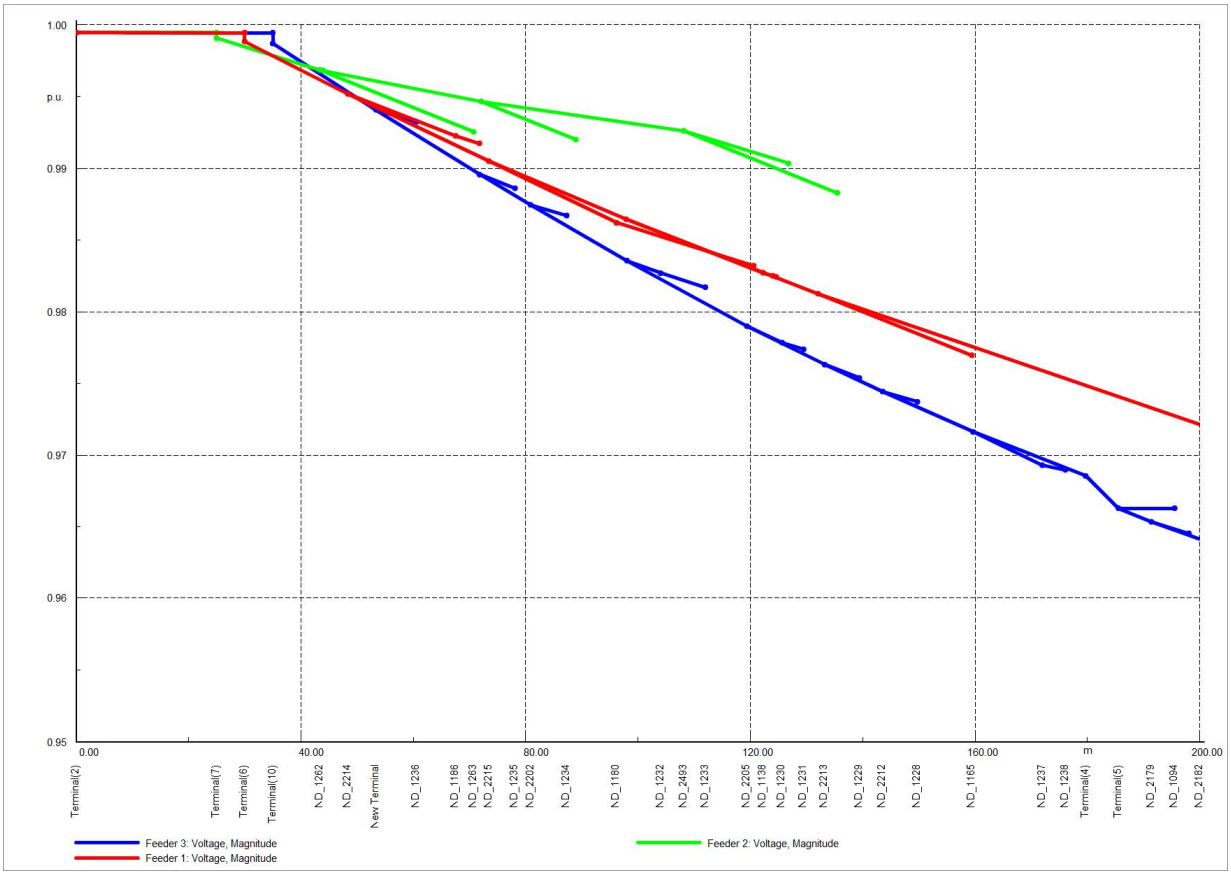
Creating Plot for Voltage Profile (Along Feeder)



Creating Plot for Voltage Profile (Along Feeder)



Results of Voltage Profile



Presentation Material 2- 8

Activity 2-3-2 Scenarios of EV Penetration

Scenarios of EV Penetration

Activity 2-3-2

JICA Expert Team

February 2025

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-2-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

Contents

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1.1 Forecasting EV Demand on the UK Electrical Grid
1.1.1 Impact of EV Market Penetration on Grid
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1.1.3 Impact of High EV Penetration on Grid
1.2 IRVE Load Forecasting in Norway
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1.2.4 Methodology for EV Load Demand Prediction
1.3 Forecasting Urban IRVE Demand in China
1.3.1 Forecasting Urban IRVE Demand in China
1.4 A Brazilian EV Demand Load Forecasting Model
1.4.1 Forecasting EV Load Demand in Brazil

1. Case Study Scenarios:

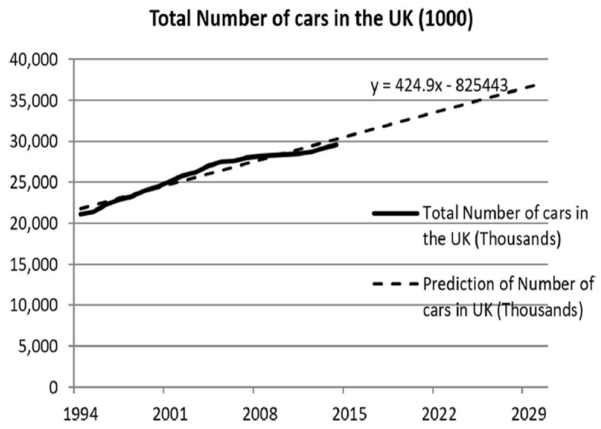
1.1 Forecasting EV Demand on the UK Electrical Grid

1.1.1 Impact of EV Market Penetration on Grid

- The study aims to estimate **EV market share** and its impact on the **UK electrical grid** by using **three scenarios** based on the projected number of **EVs** in the UK. The composition of the **vehicle fleet**, segmented by different vehicle categories based on 2018 registrations, plays a significant role in calculating the **energy demand** of the **EV fleet**. The **energy requirement** is calculated by multiplying the predicted number of vehicles by the percentage of each segment in the overall fleet, as outlined in the referenced table.
- **Problem:**
  - The UK plans to ban the sale of new petrol and diesel cars by 2030. As EV adoption increases, concerns are raised about the ability of the electrical grid to handle the increased demand.
- **Study Goal:**
  - Assess the impact of EV penetration on the grid.
  - Evaluate whether the grid can handle the increased load, particularly during peak charging times.

1.1.1 Impact of EV Market Penetration on Grid

- **Objectives:**
  - Investigate the energy demand of EVs.
  - Treat Plug-in Hybrid Electric Vehicles (PHEVs) similarly to EVs in this context.
- **Methodology Factors for Simulation:**
  - Predicted number of vehicles in the fleet.
  - Electricity required to recharge the fleet.
  - Composition of the car fleet (based on different vehicle segments).
  - Simulations examine annual electricity demand at various market penetration levels.
  - Assume EVs charge only when necessary and cover around 20 miles daily.



Total and predicted number of cars in the UK

Source: DOI.org/10.1007/s11356-022-21214-w

Composition of EVs

Vehicles by Segment	Percentage of Electric Car Fleet %
Small	35
Medium	44
Large	21

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.1 Impact of EV Market Penetration on Grid

- The study analyzes the **electricity demand** of **EVs** in the UK across **three market penetration scenarios** projected from **2014 to 2030**. In **2014**, EVs made up just **1%** of the total vehicle fleet, requiring **1 to 1.5 GW** of electricity to charge fully. The study explores three potential growth scenarios for EV penetration:
- **Growth Scenarios:**
- **Scenario 1 (Slow growth)**:
  - **EV market share increases** from **1% to 10%** by **2030**.
  - Peak demand rises to **16 GW**, over **12 times higher** than in 2014.
- **Scenario 2 (Moderate growth)**:
  - **EV market share increases** from **1% to 15%** by **2030**.
  - Peak demand reaches **24 GW** by 2030.
- **Scenario 3 (Fast growth)**:
  - **EV market share** grows to **25%** by **2030**.
  - Peak demand skyrockets to **40 GW**, more than **30 times the demand** in 2014.

1.1.1 Impact of EV Market Penetration on Grid

- **Key Findings:**
  - The timing of EV charging is crucial in determining the overall demand.
  - Without regulation, demand could rise by 50%, potentially stressing the grid.
  - A proposed solution is to control charging times to minimize grid overload
- **Grid Capacity**: The study finds that while the grid could handle up to **10% EV penetration**, challenges arise due to the **uncertainty** around future **EV production** and market responses.
- **Energy Consumption**:
  - Even under the **fast growth scenario**, the total **energy consumption** from EVs remains **relatively low** in comparison to the UK's total energy use.
    - **1% penetration** (2014): EV demand represents only **0.26%** of the UK's total energy consumption.
    - **30% penetration**: The demand would rise to **7.86%** of the total energy consumption.

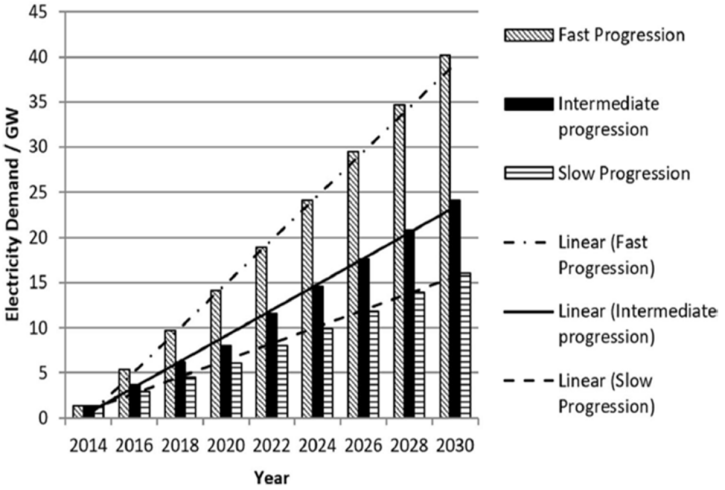
Incidence on total electrical energy consumption

Year 2030	Predicted Total Electrical Energy Consumption in the UK 2030 (350 TWH)						
Fleet Share %	1	5	10	15	20	25	30
EV Consumption ($\times 10^8$)	9.18	45.9	91.8	138	184	230	275
Incident of EVs on Total Electric Energy Consumption %	0.26	1.31	2.62	3.93	5.24	6.55	7.86

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.2 Forecasting Impact of EV Contributions to Grid

- **Process**
- Determine the daily charge demand by multiplying the number of daily charges by the number of EVs.
- Calculate the total electricity needed by multiplying the number of charges by battery capacity and efficiency.
- **Charging Time Impact**: Derive the electricity required for individual EVs based on battery capacity, charging time, and efficiency.
- **Annual Energy Demand**: Calculate yearly energy consumption by multiplying daily energy by 365 days.



Electricity Demand Prediction Model

Estimated electricity required to recharge an EV

EVs	Electricity Required by Grid (KW)	
	Domestic Charging	Fast Charging
Small	2.78	16.67
Medium	4.63	27.78
Large	6.48	38.89

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.2 Forecasting Impact of EV Contributions to Grid

- **Factors Impacting Grid Demand:**
- **EV Characteristics**: Battery capacity, range, and energy consumption per distance traveled.
- **Market Penetration**: The proportion of EVs on the road will influence grid demand.
- **Charging Types**:
  - Slow charging (6 hours) and fast charging (requires more electricity but less time) have different energy demands.
  - **Battery Efficiency**: An assumed efficiency of 90% is factored into calculations.
- **EV Categories**: Different types of EVs (small, medium, and large) with varying battery capacities and recharging times affect the load demand.

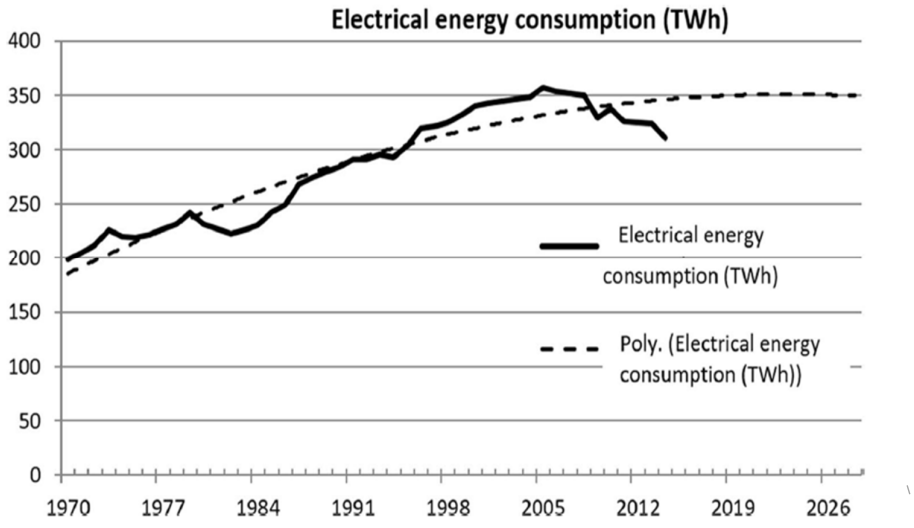
Classification of Specialized EV Groups Based on Characteristics

Segment	Battery Capacity (KWH)	Time to Charge (H)		Distance Travel (Miles)	Consumption (KWH/100 Miles)
		Domestic	Fast		
Small	15	6	1	50	30
Medium	25	6	1	80	31.25
Large	35	6	1	110	31.81

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.2 Forecasting Impact of EV Contributions to Grid

- The amount of **electricity needed** to recharge each **Electric Vehicle (EV)** is calculated using the following formulas:



Actual and predicted electrical energy consumption UK 1970–2030
(Department of Energy and Climate Change 2020)

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.2 Forecasting Impact of EV Contributions to Grid

- **Electricity Required (Eq. 1)**: Battery capacity / (Battery recharging time × Battery efficiency)
  - ➢ This formula estimates the electricity required based on the battery capacity, recharging time, and efficiency of the battery.
- **Electrical Energy Required (Eq. 2)**: Battery capacity × Time to charge × Battery efficiency
  - ➢ This formula calculates the total energy required by multiplying the battery capacity, charging time, and battery efficiency

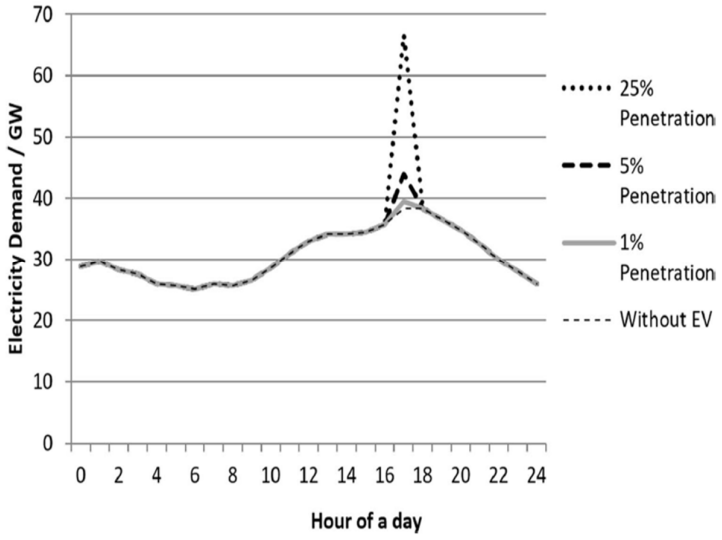
Available EVs in UK

Manufactures	Type of EVs	Battery capacity (KWH)	Average Time to Charge (H)	Average Distance Travel (Miles)	Consumption (KWH/100 Miles)
Nissan	Leaf	24	5	124	19.35
Mitsubishi	Outlander	12	5	32	35.29
BMW	i3	22	4	80	27.5
Renault	Zoe	22	6	149	14.77
Tesla	Model S	85	5	265	32.08
Kia	Soul	27	6	132	20.45
Volkswagen	E-UP	18.7	6	93	20.11
Ford	Focus-Electric	23	5	76	30.26
Audi	E-Tron	71	7	150	47.33

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.3 Impact of High EV Penetration on Grid

- The **UK's electricity demand** typically experiences **daily peaks**, with the highest demand occurring between **16:00 and 20:00**.
- **Impact of Uncontrolled Charging:**
- **At 25% EV market penetration**, daily full charging of all EVs could increase demand by **30 to 40 GW**, causing **significant spikes** in electricity usage.
- This **additional demand** could strain the grid, especially during **peak hours**.



Impact on daily demand during uncontrolled charging

Source: DOI.org/10.1007/s11356-022-21214-w

1.1.3 Impact of High EV Penetration on Grid

- **Managing Demand:**
- To **prevent overload**, **EV charging must be coordinated** using a **smart metering system**, ensuring that charging occurs primarily during **off-peak hours**.
- Without this coordination, the grid would require **costly upgrades**, which would increase **expenses** for **distribution operators** and ultimately **consumers**.
- **Conclusion:**
- While the overall impact on **annual energy consumption** remains relatively small, the **time-of-day charging habits** of EVs could significantly affect **grid demand**.
- Effective **charging time management** is crucial, particularly with **25-30% EV penetration**, to avoid **excessive daily power demand**.

1.2 IRVE Load Forecasting in Norway

1.2.1 Vulkan IRVE Smart Charging

- **Background:**
  - Project Location: Data from a three-year pilot project conducted at the Vulkan parking garage in Oslo, Norway. This site is one of the largest hybrid-EV charging hubs in Europe.
  - Project: Part of the European Interreg North Sea Region (NSR) SEEV4-City initiative.
  - Location: Vulkan estate, 1 km from Oslo city center.
  - Capacity: 102 EV charging connectors and a stationary battery storage system.
  - Area: Mixed-use space with market halls, shops, restaurants, cafes, hotels, and residences.
  - Significance: Key hub for EV charging in Oslo, supporting clean energy and EV adoption.
- **Forecasting Approach:**
  - Model Used: Long Short-Term Memory (LSTM) regression network was employed to predict hourly EV charging demand.
  - Accuracy: The model achieved a Weighted Absolute Percentage Error (WAPE) of 30.5%.

1.2.1 Vulkan IRVE Smart Charging

- **Key Findings and Insights:**
  - Peak Demand and Smart Charging Needs:The analysis highlights the critical need for smart charging solutions to manage peak charging demand, specifically between 19:00 and 21:00.
- **Uneven Distribution of Charging Station Usage**:
  - **DC Charging Stations**: These stations experienced higher utilization rates.
  - **AC Charging Stations**: Though they had more charging sessions, their usage was comparatively less intensive.
- **Extended Parking Times**:
  - The study observed that vehicles stayed parked at charging stations for longer than necessary, suggesting opportunities for optimizing charging performance.
- **Data Sources and Techniques:**
  - Data Collected:
    - Real-time charging data from the Vulkan parking garage.
    - Data from other European projects focused on EV charging behaviors and patterns.
  - Advanced Techniques for Analysis:
    - **Data Processing and Clustering**: Used to analyze charging patterns.
    - **Deep Learning Methods**: Employed to forecast charging behavior and predict demand.

1.2.1 Vulkan IRVE Smart Charging

- **Smart Charging Insights**:
  - Optimizing Grid Performance: A deeper understanding of charging demand is essential to develop smart charging schemes that reduce grid strain, especially during peak hours.
  - Battery Health: Smart charging practices also help in maintaining the long-term health of EV batteries.



(a) (b) (c)

(a) Google Earth image of Vulkan estate within Oslo;
(b) zoomed-in image; (c) the main entrance

Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

1.2.2 Overview of the Vulkan IRVE Data

- This table offers a clear overview of the Vulkan EV parking garage's key infrastructure, charging system, and data collection processes, highlighting their role in enhancing smart charging solutions and optimizing grid management.

Summary of the Key Points of Vulkan parking garage in Oslo

Category	Details
Facility Overview	Vulkan EV parking garage is one of the largest EV charging garages in Norway and the North Sea region, with 450 parking spaces, of which 102 are dedicated to EVs. It serves residents, public users, and commercial companies.
Charging Infrastructure	Includes 50 AC Type 2 chargers (3.7 kW to 22 kW), 2 rapid DC chargers (50 kW), and a Battery Energy Storage System (BESS) with 50 kWh capacity for peak demand shaving. Chargers are spread across three floors.
Smart Charging	Uses **Ferroamp cloud-based energy management system** to balance energy supply and demand. The system manages charging speed based on grid load and enables users to select charging speeds via an app at a differential price.
Data Collection	A total of **10,092 charging sessions** recorded from **2017-2019**. Data includes connection/disconnection times, energy charged, and station details.
Charging Event Dataset	The dataset contains detailed information about each charging session: start/end times, energy charged, and session duration.
Spatial-Temporal Distribution	Charging demand varies across different charging stations, with peak demand occurring from **19:00-21:00**. The smart system reduces load during peak times. The parking time at charging stations exceeds charging requirements, creating an opportunity for optimization.
Charging Station Utilization	DC fast chargers have **higher utilization** but AC chargers are more numerous. **70.2% of stations are AC**, ensuring flexibility in charging speed and duration.
Demand Forecasting	An **LSTM regression model** predicts hourly charging demand, achieving **RMSE of 24.5 kW** and **WAPE of 30.5%**, helping to plan for peak demand and grid stability.
Grid Stability	Smart charging helps align charging with renewable energy availability, reducing **grid instability** by managing charging loads, especially during peak demand times.
Implications for EV Adoption	The smart charging infrastructure helps mitigate grid overload, reduce local grid reinforcement costs, and enhance **cost efficiency** and **sustainability** as EV adoption increases.

Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

1.2.3 EV Charging Behavior and Analysis Summary

■ EV Charging User Behavior Clustering :

- The dataset from the Vulkan EV parking garage, which includes data on connection times, energy consumption, and session durations for both AC and DC chargers, was analyzed across five key dimensions to understand charging behaviors and optimize demand forecasting:
  - **Charging Time Distribution**
  - **Charging Power Analysis (per session)**
  - **Charging Pattern and Clustering**
  - **Spatial-Temporal Utilization of Charging Stations**
  - **Seasonal Load Profile Analysis**
- The data was processed to eliminate outliers and reformatted for advanced analysis, including clustering, correlation, and regression, primarily aimed at improving forecasting accuracy.

1.2.3 EV Charging Behavior and Analysis Summary

Table: EV charging event data

Attribute Name	Unit	Description
Device ID	Text string	the ID of the charging station
Connector ID	Text string	1 or 2, indicating which connector of an EV charger is used
Device type	Text string	to indicate the type (AC or DC) of a charger
Connection time	yyyy-mm-dd HH:MM: SS	When the EV is connected to the charger
Disconnection time	yyyy-mm-dd HH:MM: SS	When the EV is disconnected to the charger
Energy charged	KWH	Energy (Electricity) consumed to charge the EV

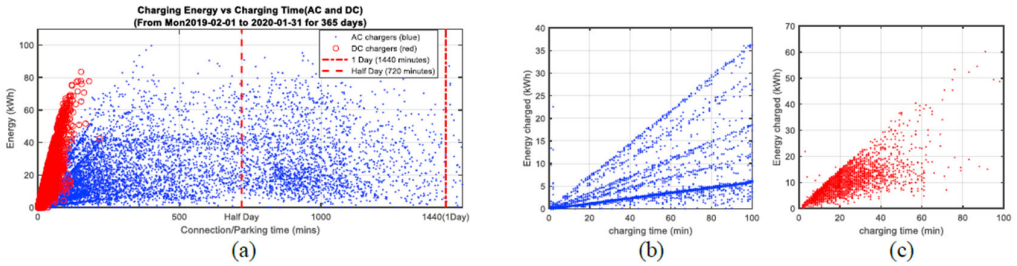
Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

■ Key Findings:

- Energy Charged vs. Connection Time:
  - **DC Charging**: Sessions are shorter but consume more energy compared to AC chargers. Frequent charging events are observed in the sub-200-minute range.
  - **Residential Charging Pattern**: Dense activity is noted in the 800–1,000-minute range, linked to overnight residential charging (typically from 6 p.m. to 9 a.m.).
  - **Connection Time**: Connection times often exceed actual charging durations, especially during overnight charging.

1.2.3 EV Charging Behavior and Analysis Summary

- **Charging Power Analysis**:
  - **AC Chargers**: Distinct linear charging patterns are identified at various power levels (3.7 kW, 7.4 kW, 11 kW, 22 kW).
  - **DC Chargers**: The highest observed charging power is 40 kW, slightly lower than the rated 50 kW.
- **Forecasting with LSTM**: A Long Short-Term Memory (LSTM) model demonstrated strong forecasting capabilities, achieving reasonable accuracy in predicting hourly charging demand (RMSE measurement).

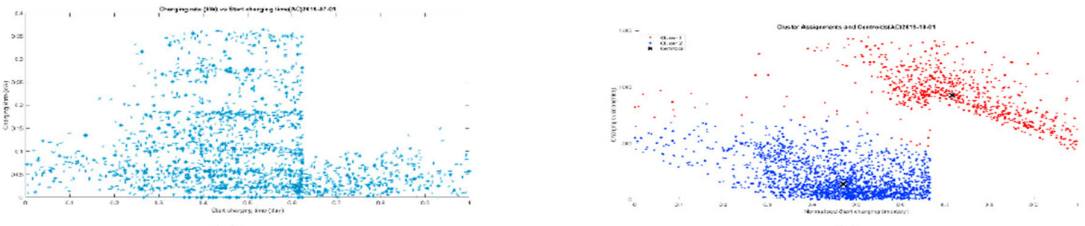


(a) Overview of the EV charging demand vs. connection time in a year 2019-2020;
(b) EV demand (AC) for connection time less than 100 minutes;
(c) EV demand (DC) for connection time less than 100 minutes.

Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

1.2.3 EV Charging Behavior and Analysis Summary

- **The analysis of EV charging data reveals distinct charging patterns influenced by the time of day and the type of user:**
  - **Daytime (Business Users):** From 6 a.m. to 4 p.m., charging stations are predominantly used by business users. Charging rates vary from 3.7 kW to 22 kW for AC chargers, reflecting a broad range of charging demands during business hours.

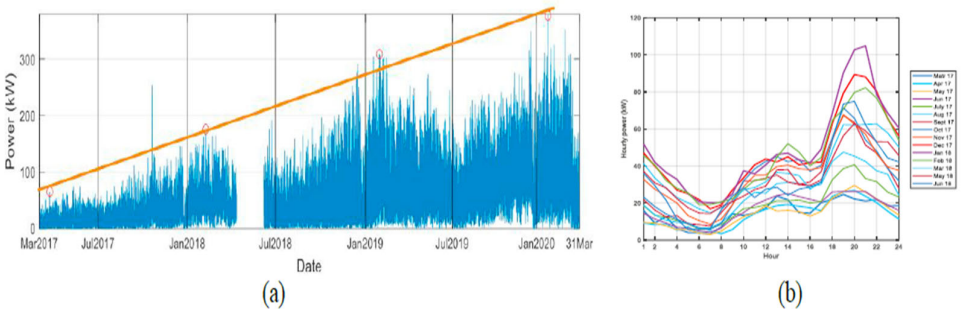


Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

  - **Night-time (Residential Users):** From 4 p.m. to midnight, residential users take over the charging stations. These sessions typically show lower charging rates compared to business users, indicating that residential users tend to charge their vehicles overnight.
  - **Clustering Analysis:** A k-means clustering algorithm was employed to identify these patterns.
    - **Residential Users (Red Dots)**: Exhibit lower charging rates during nighttime charging.
    - **Business Users (Blue Dots)**: Display a wider distribution of charging rates throughout the day.

1.2.3 EV Charging Behavior and Analysis Summary

- **Demand Forecasting for Smart Charging**
  - **Seasonal Load Profile Analysis:** The Seasonal Load Profile Analysis shows rising energy demand over time, with peak demand in winter. This highlights the need for smart charging to manage grid load efficiently during high-demand periods.



(a) The aggregated EV charging load during a 3-year period (02/03/2017-31/03/2020).
(b) the aggregated daily EV charging profile (monthly averaged).

Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

1.2.4 Methodology for EV Load Demand Prediction

- **Methodology of LSTM Deep Learning** :This study leverages **Long Short-Term Memory (LSTM)** networks to forecast hourly EV demand, which is essential for effective grid management and optimizing smart charging strategies.
  - **LSTM Overview**: LSTM, an advanced form of **Recurrent Neural Networks (RNN)**, is highly effective for time-series forecasting. It captures both short-term and long-term dependencies, making it ideal for predicting EV charging demand.
  - **Model Setup**: The study uses 3,710 hourly EV demand data points from November 2018 to April 2019.

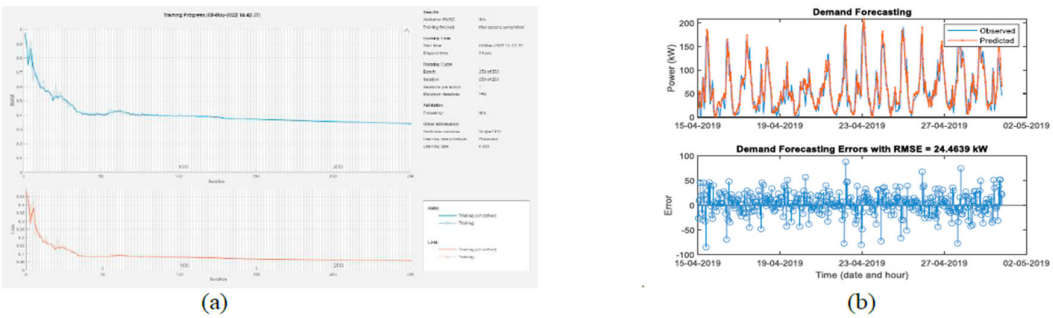


Figure: (a) Training process of the proposed LSTM for EV charging energy demand forecasting;
(b) EV energy charging demand forecasting by the proposed LTSM (top),
and the prediction errors

Source: Data-Driven EV Charging Load Forecasting and Smart Charging, Xuewu D. et. al., ScienceDirect, 2023

1.2.4 Methodology for EV Load Demand Prediction

- The data was split into a **90% training set** and a **10% test set**. The LSTM model was set with **12 hidden units** to predict future demand.
- **Performance**: The model achieved a **Standardized Root Mean Square Error (RMSE)** of **0.40**, demonstrating its predictive accuracy. It also recorded a **Weighted Absolute Percentage Error (WAPE)** of **30.5%**, effectively capturing trends, fluctuations, and peak usage times.
- **Findings**: LSTM is successful in predicting **seasonal variations** in EV demand and accurately captures peak usage periods. The model adapts to changing data over time, correcting errors and continuously improving its forecasting performance, thus offering a reliable method for **demand forecasting** and **grid optimization**.

1.3 Forecasting Urban IRVE Demand in China

1.3.1 Forecasting Urban IRVE Demand in China

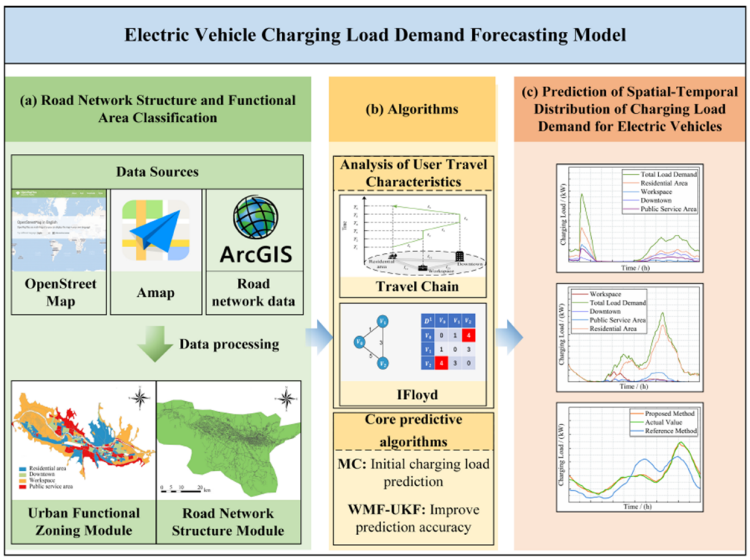
- This study focuses on improving the accuracy of EV load demand forecasting by considering spatial and temporal factors. It introduces a new approach using the **WMF-UKF algorithm**, which integrates various data sources to improve forecasting and optimize charging facility placement. This method also ensures grid stability.
- **Main Key Aspects of the Proposed Method:**
  - **WMF-UKF Algorithm**: A non-linear filtering technique that combines multiple data sources, reducing errors and improving forecasting accuracy through enhanced state estimation.
  - **Urban Functional Zones**: The city is divided into four zones (residential, downtown, workspace, and public services) to assess how EV charging demand varies by zone.
  - **Road Network Modeling**: Traffic flow, travel time, and path selection are modeled using road network topology to understand how infrastructure impacts charging demand.

1.3.1 Forecasting Urban IRVE Demand in China

- **Methodology:**
  - **Urban Zoning & Data Integration**: POI data, night-time lighting, and social data from platforms like Amap, OpenStreetMap, and Tencent are used to predict charging demand based on spatial differences in the city.
  - **Road Network Modeling**: OpenStreetMap data is used to create a road network model that considers highways, major roads, and minor roads.
  - **Travel Characteristics**: The model integrates trip behavior, including trip chains and the state of charge (SOC) of EV batteries. It also differentiates between simple and complex trips.
  - **Battery SOC Influence**: Charging patterns are influenced by the EV's battery charge level, as users are more likely to charge when battery mileage is low.
  - **Mileage and EV Distribution**: Daily mileage and trip data, analyzed using SPSS, help identify trends in charging behavior on different days of the week.

1.3.1 Forecasting Urban IRVE Demand in China

- **Method Validation:**
- The method was validated by comparing its predictions with actual traffic data, demonstrating strong forecasting accuracy. This provides key insights for grid operations, charging station management, and urban planning, helping optimize charging infrastructure in urban areas.



Structural diagram

Doi.org/10.3390/en17174505

1.4 A Brazilian EV Demand Load Forecasting Model

1.4.1 Forecasting EV Load Demand in Brazil

- **This study focuses on forecasting electric vehicle (EV) energy demand in Brazil**, where EV market penetration is still in its early stages. It critiques earlier models that used average charging times and distances, which didn't consider varied travel behaviors. The study proposes a more accurate approach by simulating different EV penetration levels and evaluating their effects on the local energy grid, especially on transformers, to guide infrastructure planning.
- **Methodology:**
  - **Modeling Approaches**: Earlier deterministic models failed to capture EV usage variability. This study uses **stochastic models** to simulate real-world EV usage more accurately.
  - **Data Sources**: the study uses **travel survey data** on frequency, reasons, time, and mileage to model EV demand, including different EV types like **EVs** and **PHEVs**, focusing on battery capacity, State of Charge (SoC), and charging power.
  - **Multi-Level Charging**: The model incorporates **multi-level charging** to reflect variability in real-world charging needs based on different EV models' charging specifications.

1.4.1 Forecasting EV Load Demand in Brazil

- **Multi-Level Charging**: The model incorporates **multi-level charging** to reflect variability in real-world charging needs based on different EV models' charging specifications.

- **Grid Load Impact**: the study assesses the impact of EV charging on the **residential load curve** and **transformer loading**. It uses **Monte Carlo Simulation (MCS)** to model EV battery charging and transformer loading, with probability distributions from survey and residential data.
- **Probabilistic Approach**: A **probabilistic approach** is used to model charging demand and transformer loading, providing accurate forecasting, especially for areas with limited charging infrastructure.

EV Characteristics

Type	Vehicle Type	Battery Capacity (KWH)	Range (KM)	Fuel Consumption (KWH/KM)
Nissan Leaf	EV	40.0	240.0	0.188
Chevrolet Bolt	EV	60.0	380.8	0.175
Renault Zoe	EV	41.0	232.0	0.163
Tesla Model 3	EV	62.0	422.4	0.169
BMW i3s	EV	42.2	201.6	0.200
Toyota Prius	PHEV	8.8	40.0	0.156
Ford Fusion	PHEV	7.0	41.6	0.206
Porsche Cayenne	PHEV	14.1	30.4	0.394
BMW i8	PHEV	11.7	43.2	0.216
Volvo XC90	PHEV	10.4	22.4	0.356

Source: EV Demand Forecasting Model Based on Travel Survey: a Brazilian Case Study, Sausen, J. et. al., IEEE Xplore, 2019

1.4.1 Forecasting EV Load Demand in Brazil

■ Key Steps in the Forecasting Methodology:

- **EV Demand Forecasting Model**: The model selects **11 EVs** (5 BEVs, 6 PHEVs) based on characteristics like range, battery capacity, and charging power. Charging needs are estimated using probability distributions based on trip frequency, purpose, time, distance, and charging level.
- **Trip Frequency and Reason Estimation (PDF)**: **Weekly probability distributions** estimate how often each EV travels, categorizing trip distances by purpose (work, shopping, etc.) to calculate weekly mileage.
- **Charging Level and Time Determination**: The model estimates the **State of Charge (SoC)** and determines the appropriate charging level (Level 1 or Level 2). Charging duration is calculated based on battery specs and charging level.
- **Trip Time Estimation**: **Charging time** is estimated using a probability distribution based on trip reasons and typical charging durations.

Table: TRIP Reason, Distance Driven and Duration

Reason		PDF (%)	Average Distance (KM)	Average Duration (Min)
A	Work	56.69	26.6	37.7
B	Shopping	14.54	16.8	31.1
C	Study	10.30	19.0	33.4
D	Healthcare	9.55	22.8	38.7
E	Others	8.92	16.8	31.1

Source: EV Demand Forecasting Model Based on Travel Survey: a Brazilian Case Study, Sausen, J. et. al., IEEE Xplore, 2019

Presentation Material 2- 9

Activity 2-3-3 Methodology for Electricity Demand Forecast of EV (Global)

Methodology for Electricity Demand Forecast of EV (Global)

Activity 2-3-3

JICA Expert Team

February 2025

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-2-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

Contents

1. Methodology for Forecasting Electricity Demand
1.1 Navigating Forecasting IRVE Load Demand
1.2 Introduction to Forecasting IRVE Demand
1.3 IRVE Demand Forecasting Methods
1.3.1 Deep Learning, Monte Carlo and ArcGIS

1. Methodology for Forecasting Electricity Demand

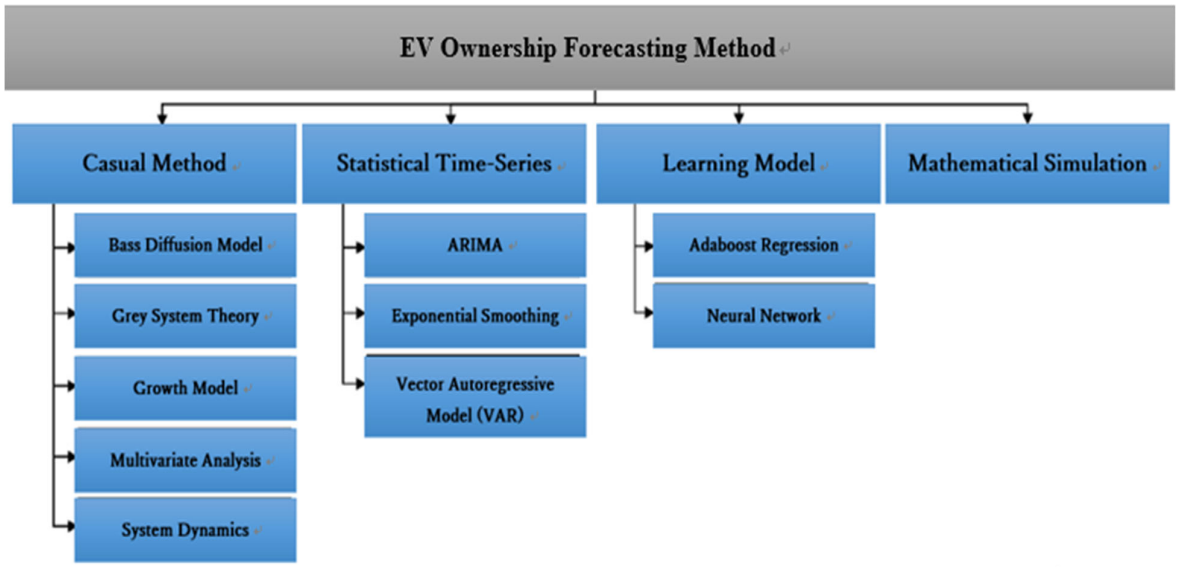
1.1 Navigating Forecasting IRVE Load Demand

- Accurate forecasting of IRVE load demand is crucial for power system operators to effectively manage energy in smart cities, IRVE charging networks, and ensure proper energy distribution.
- Proper load demand forecasting helps with integrating EVs into energy systems, optimizing scheduling, and balancing supply and demand.
- Recent modeling methods for IRVE load demand include both linear and nonlinear models to analyze time series data for accurate predictions.
- Smart charging strategies are essential for grid stability, managing energy demand, and avoiding costly infrastructure upgrades.
- Innovative forecasting techniques aim to address current model limitations, capturing the spatial and temporal variability in EV charging demand.
- A major challenge is the scarcity of publicly available data on user-specific driving behaviors and regional energy needs, limiting the accuracy of load forecasts.
- Existing datasets, mainly limited to operational data from IRVE chargers, restrict the precision of forecasting models.

1.1 Navigating Forecasting IRVE Load Demand

- **EV Penetration and Ownership Forecasting Methods** are categorized into four main techniques:
  - **Causal Method**
  - **Statistical Time-Series**
  - **Learning Model**
  - **Mathematical Simulation**
- **Long-term EV charging load forecasts** are critical for infrastructure planning.
- **Short-term predictions** are important for aligning EVs with renewable energy sources.
- **Causal methods**, including **diffusion models** and **multivariate statistical analysis**, are the most widely used techniques.
- The rise of **big data** and **data mining** is driving the use of **machine learning** and **neural networks** for predicting EV adoption.

1.1 Navigating Forecasting IRVE Load Demand



Overview of relevant norms and standards in the field of charging of electric vehicles.

Source: Forecasting Methods for Electric Vehicle Ownership: A Literature Review," Bunga K. et al., ScienceDirect, ISICO, 2023.

1.2 Introduction to Forecasting IRVE Demand

- **Objective:** Predicting EV charging demand is critical for optimizing grid management and infrastructure development.
- **Key Factors:** Temporal and spatial characteristics of EV trips influence charging demand.

1. Key Characteristics of EV Charging Demand

- **Temporal Factors:** Variations in travel times (start time, duration, stop time, end time) impact charging demand.
- **Spatial Factors:** Destination types (residential, work, commercial) and travel distances affect when and where EVs need to charge.

2. Modeling Travel Patterns and Charging Behavior

- **User Travel Destinations:**
  - **Residential Areas:** Extended parking time, ideal for overnight charging.
  - **Work Areas:** Moderate parking time, suitable for daytime charging.
  - **Commercial Areas:** Short parking time, requiring fast charging solutions.
- **Travel Chain Model:** Captures the sequence of travel activities, helping understand EV user behavior.

1.2 Introduction to Forecasting IRVE Demand

3. State of Charge (SOC) and Charging Behavior

- **SOC Calculation:** Based on energy consumption and travel distance, influencing daily charging needs.
  - Assumption: EVs typically charge once per day, with SOC affected by daily mileage.
- **Charging Behavior:**
  - Typically occurs after returning home.
  - Commercial areas require fast charging due to shorter parking durations.

4. Monte Carlo Simulation for Charging Load Forecasting

- **Purpose:** Monte Carlo simulations provide probabilistic forecasts of charging load demand.
- **Process:**
  - Input parameters: EV ownership data, vehicle performance, SOC distribution, charging intervals.
  - Simulations: Model daily charging demand in different areas (residential, work, commercial).
- **Outcome:** Repeated simulations offer more accurate and reliable charging demand predictions.

1.2 Introduction to Forecasting IRVE Demand

5. Charging Station Load Profile Forecasting

- **Factors Influencing Load Profiles:** Penetration rates, EV market share, SOC post-charging, driving distances, charging rates, station arrivals/departures.
- **Objective:** Forecast daily charging station load profiles to optimize grid balance between constant current (CC) and constant voltage (CV) loads.
- **Sensitivity Analysis:** Assesses the impact of variations in input factors on charging station loads and grid performance.

1.3 IRVE Demand Forecasting Methods

- **Linear Models:**
- **Autoregressive Moving Average (ARMA):**
  - **ARMA models** use past data trends to forecast future EV charging demand, effectively capturing **seasonality**.
  - **ARIMA** (Auto-Regressive Integrated Moving Average) and its variations like **SARIMA** (Seasonal ARIMA) and **FARIMA** (Fractional ARIMA) provide more accurate predictions.
  - **SARIMA** is ideal for both **short-term** and **long-term forecasting**.
  - **ARIMA** works well when forecasting demand for **non-residential EV charging equipment**, especially with **aggregated data**.
- **Multiple Linear Regression (MLR):**
  - **MLR** examines how multiple factors, such as **driver behavior** and **battery levels**, influence EV energy use.
  - This approach is useful for **optimizing charging schedules** and **predicting demand**.
- **Principal Component Analysis (PCA):**
  - **PCA** simplifies complex data by **reducing its dimensions**, improving the performance of forecasting models.

1.3 IRVE Demand Forecasting Methods

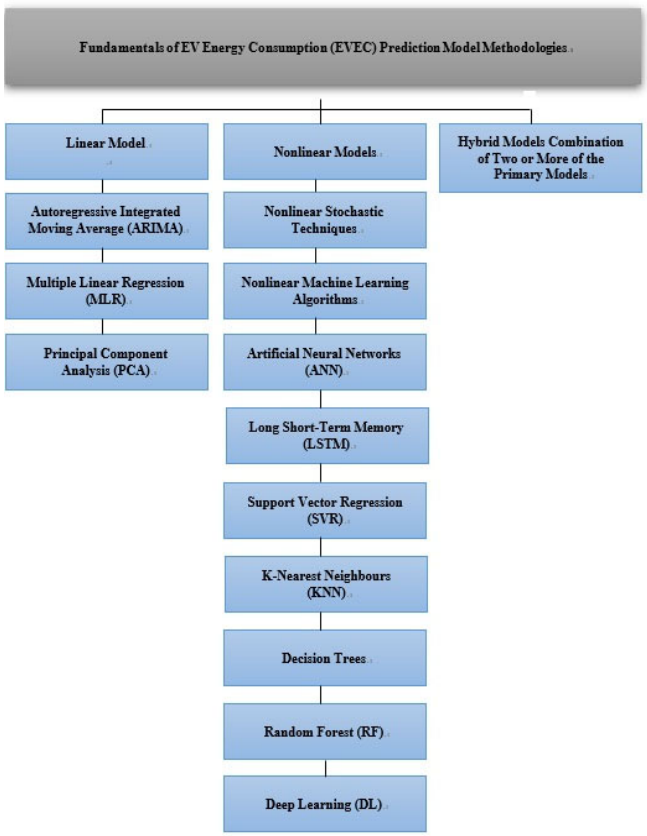
- **Nonlinear Models:**
- **Stochastic Non-Linear Approaches:**
  - These models are effective for forecasting when data exhibits **nonlinear patterns**, offering more **accurate predictions** for EV energy demand.
- **Machine Learning Techniques:**
  - **Artificial Neural Networks (ANNs):** Deep learning models, like **autoencoders** and **deep belief networks**, are increasingly used for **EV load forecasting**, outperforming traditional methods.
  - **Support Vector Regression (SVR): SVR** helps identify **nonlinear relationships** in EV demand by transforming input data into **higher-dimensional spaces**.
  - **K-Nearest Neighbor (K-NN): K-NN** makes predictions based on the closest data points in historical datasets, aiding in **charging demand forecasting**.
  - **Deep Learning (DL): Deep learning models** handle **large datasets** and account for **variability** in EV behavior, improving prediction accuracy.
- **Traffic Flow Forecasting with CNN & PIS:**
  - **Convolutional Neural Networks (CNNs)** are trained to **predict traffic flow patterns**, while **Prediction Intervals (PIs)** address uncertainties, refining predictions for **fast-charging stations**.

1.3 IRVE Demand Forecasting Methods

- **Decision Trees (DTs) and Random Forests (RFs):**
  - These models are well-suited for analyzing **complex data relationships**. **Random Forests (RFs)** enhance prediction accuracy by combining the results of **multiple decision trees**.
- **Monte Carlo Simulation:**
  - This technique uses **probabilistic models** to simulate **variability**, which helps in **forecasting EV charging demand** with more accuracy by accounting for **random factors**.
- **Queuing and Traffic Flow Theory:**
- **EV Arrival Rate Estimation:**
  - The **rate at which EVs arrive** at charging stations depends on factors like their **state-of-charge** (SOC) and **travel behavior**, which influence the **overall charging load**.
- **Markov MMCK Model:**
  - This model simulates charging scenarios with **limited station capacity**, accounting for situations where **EVs may leave** due to **full capacity** or **long wait times**.

1.3 IRVE Demand Forecasting Methods

- **Queuing Theory:**
  - **Queuing theory** helps optimize **charging station operations** and **Vehicle-to-Grid (V2G) integration** by considering key factors such as **charging duration**, **travel distance**, and the overall system's capacity to handle demand.



Fundamental EVEC Prediction Approaches.

Source: DOI: 10.1109/ACCESS.2022.0122113

1.3.1 Deep Learning, Monte Carlo and ArcGIS

- This approach combines multiple advanced techniques to enhance the accuracy and applicability of **EV charging demand forecasting**:
- **Monte Carlo Simulation**: Accounts for **variability** in **EV charging behavior** by simulating different possible outcomes, improving the reliability of forecasts.
- **Deep Learning**: Uses models like **Auto-former**, **Long Short-Term Memory (LSTM)**, **Recurrent Neural Networks (RNN)**, and **Gated Recurrent Units (GRU)** to improve prediction accuracy, especially for fast-charging stations.
  - These models excel at learning **long-term dependencies** in **time-series data**, capturing patterns in charging demand over time.
  - **Auto-former**: A transformer-based deep learning model that outperforms LSTM by decomposing time-series data into **seasonal** and **trend components**, resulting in more accurate **long-term forecasts**.
- **ArcGIS**: Applies the forecasts in a **geospatial context**, factoring in **charging station locations**, **traffic**, and **regional dynamics**, ensuring the forecasts are relevant to specific areas.

1.3.1 Deep Learning, Monte Carlo and ArcGIS

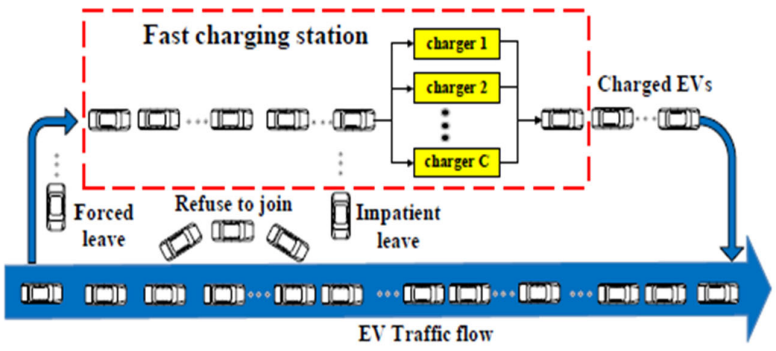
- **Key Steps in Improving Forecast Accuracy:**
- **Data Collection and Analysis**: Gathering and analyzing relevant data to understand patterns and trends in EV charging demand.
- **Travel Behavior Analysis**: Studying how **user travel patterns** impact charging demand, including trip length, time of day, and location.
- **Prediction Enhancement**: Using advanced techniques like **deep learning** and **Monte Carlo Simulation** to refine forecasts.
- **Validation Against Traffic Survey Data**: Comparing the predictions with **real-world data** from **traffic surveys** to ensure the accuracy of the forecasts.
- By combining these factors with advanced algorithms like **Monte Carlo simulation**, the model provides a more effective forecast for **EV load prediction**. This helps improve **grid operations** and supports **urban planning efforts**, ensuring a more efficient and optimized approach to managing charging infrastructure.

1.3.1 Deep Learning, Monte Carlo and ArcGIS

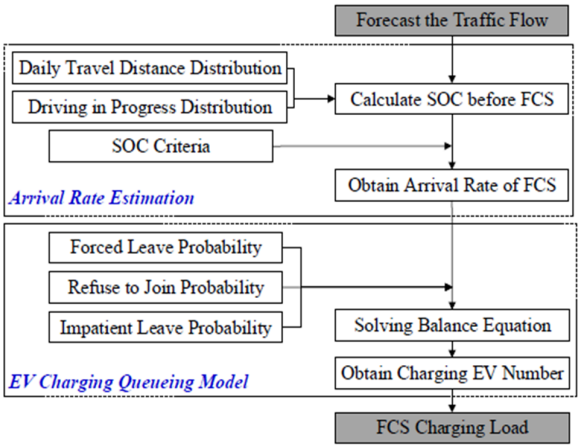
- **Monte Carlo Simulation for IRVE Forecasting**
- **Determining EV Parameters**: First, the number of **EVs** and their key parameters (such as **battery capacity** and **charging power**) are defined.
- **Random Sampling**: Charging start times and **state of charge (SOC)** values are selected randomly based on **probabilistic models**, helping to calculate the **charging duration**.
- **Simulating Recharging Behavior**: Post-trip recharging behavior is simulated while recording **driving patterns**, influencing the timing and amount of charge needed.
- **Summing Charging Demand**: The total charging demand is summed over **24 hours** at **1-minute intervals** to predict regional **charging needs**.
- Monte Carlo simulations is a **statistical method** that applies **random sampling** to predict **EV charging loads**. Since **SOC** is **stochastic** (depends on the current state and transition probability), this method improves **EV charging load predictions**, aiding in **infrastructure planning** and **optimization**.

1.3.1 Deep Learning, Monte Carlo and ArcGIS

- An **ArcGIS-based prediction model** integrates **road network structures** and **traffic congestion analysis** to forecast EV charging loads. It considers factors such as:
- **Vehicle Size**
- **Charging Modes**
- **Operational Patterns**
- **Battery Characteristics**
- **Tariff Systems**



Capacity constrained queuing model that considers driver behaviours.



Flowchart of the FCS charging load determination.

Source: Deep Learning-Based Probabilistic Forecasting of Electric Vehicle Charging Load with a Novel Queuing Model, Xian Z. et. al., IEEE, 2020

Presentation Material 2- 11

Activity 2-3-3 Methodology for Electricity Demand Forecast of EV (Japan)

Methodology for Electricity Demand Forecast of EV (Japan)

Activity 2-3-3

JICA Expert Team

September 2025

Japan International Cooperation Agency

Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-2-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

Contents

1. Forecasting Electricity Demand for EV in Japan: Methodologies and Tools
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   1.2 R&D Support for EV Load Forecasting in Japan
   1.3 Forecasting EV Electricity Demand in Japan
2. EV Charging Demand Forecast Modeling in Japan
   2.1 EV Demand Forecasting Simulation Framework
   2.2 Simulation Outcomes
   2.3 Modeling Power Distribution System for EV
3. Case Study: Development of Analytical Models for EV Charging Demand
   3.1 From Traffic Patterns to Grid Load Analysis
   3.2 Development of Traffic Simulation Model
   3.3 EV Demand Curve Modeling Outcomes
   3.4 Development of Distribution System Models
   3.5 Case Study: Osaka Prefecture

1. Forecasting Electricity Demand for EV in Japan: Methodologies and Tools

1.1 Overview of EV Demand Modeling Tools

- Japan employs advanced modeling tools to support EV infrastructure planning, emphasizing spatial optimization, demand forecasting, and user behavior simulation. Developed by research institutes and engineering firms, these models underpin national strategies like the "EV-PHV Roadmap."

- They help planners identify ideal locations for charging stations, predict peak electricity demand from EVs, and simulate interactions among drivers, vehicles, and infrastructure.

- Together, these tools facilitate the design of an efficient, user-focused charging network aligned with Japan's broader electrification and decarbonization goals.

1.1 Overview of EV Demand Modeling Tools

- EV-OLYENTOR (CRIEPI & Kozo Keikaku Engineering) optimizes the placement of EV quick-charging stations using traffic simulations based on origin–destination data, supporting national and regional planning with real-world mobility insights.

- The Stochastic EV Charging Demand Model employs Monte Carlo methods in MATLAB to forecast public charging demand by accounting for variability in user behavior, trip distances, and energy use, helping anticipate infrastructure bottlenecks.

- The Multi-Agent Trip Simulation Model leverages agent-based simulations (e.g., MATsim) with real trip survey data to produce high-resolution spatial and temporal forecasts of EV charging demand, enabling precise charger siting and informed.

1.2 R&D Support for EV Load Forecasting in Japan

- Japanese EV modeling tools stand out by integrating detailed traffic simulations and stochastic behavioral data, focusing on transportation electrification at a fine scale.
- This contrasts with broad macro-level models like the IAEA's MAED-2 or the U.S. EVI-Pro Lite tool, which provide complementary but less granular insights.
- Leading companies such as Hitachi, Toshiba, and NEC develop AI-driven smart grid platforms incorporating EV load forecasting tailored to Japan's unique grid conditions. Meanwhile, NEDO funds R&D advancing proprietary EV forecasting models and integrated energy management solutions.
- Japanese utilities often adapt global grid simulators like OpenDSS and GridLAB-D for local use. Together, this ecosystem reflects Japan's commitment to customized, AI-enhanced tools supporting EV infrastructure and grid stability.

1.3 Forecasting EV Electricity Demand in Japan

- Forecasting EV electricity demand in Japan employs an integrated approach combining agent-based transport simulations, power system analysis tools, and statistical/machine learning models.
- Agent-based models (e.g., MATSim and its variants) are widely used to simulate vehicle movements, charging behavior, and trip chains, capturing detailed spatial-temporal patterns of EV usage.
- Power system simulators (such as PSCAD, PSS®E, OpenDSS) analyze grid impacts, peak loads, and infrastructure needs based on EV charging profiles.
- Machine learning and statistical models complement these by forecasting aggregate electricity demand using historical data and scenario analyses.
- The combined use of these tools enables a comprehensive evaluation of EV integration effects on electricity demand, infrastructure requirements, and grid stability.
- In Japan, multi-tool integration is essential to address regional variations, logistics characteristics, and renewable energy fluctuations in demand forecasting.

2. EV Charging Demand Forecast Modeling in Japan

2.1 EV Demand Forecasting Simulation Framework

- Electric vehicles (EVs) are central to Japan's strategy for achieving carbon neutrality by 2050.
- However, as EV adoption expands, the increased demand from widespread use of both regular and fast chargers may strain local electricity distribution networks.
- Potential impacts include concentrated loads, grid congestion, and voltage instability.
- To address these issues, Japan has launched simulation-based studies to evaluate how EV charging affects distribution system performance and to identify effective countermeasures.

2.1 EV Demand Forecasting Simulation Framework

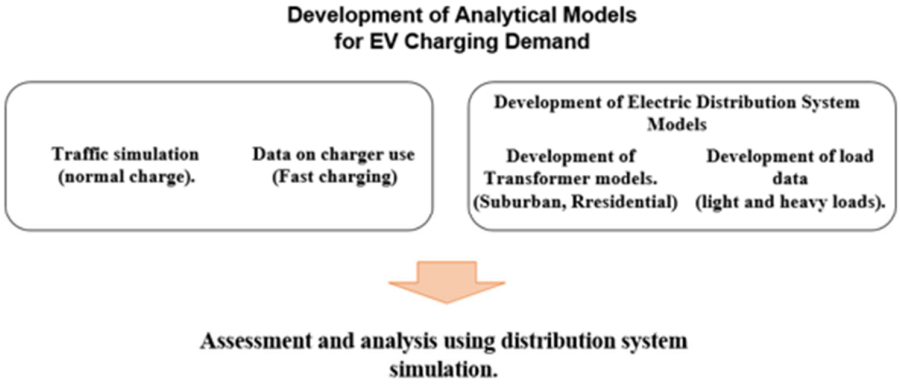
- The assessment methodology involves building detailed analytical models of EV charging demand and simulating their interaction with the electricity distribution system. The simulation process includes:
- **Creating EV Charging Demand Curves:** Based on traffic simulations and surveys, daily time-series demand data are generated for regular residential and workplace charging (Ex. from Osaka Prefecture).
- **Model Inputs:**
  - **Traffic Simulation Data** (vehicle movement and usage patterns)
  - **Vehicle and User Profiles** (from census and technical specs)
  - **Charging Infrastructure Use** (sample data from fast charger operators)
- **Distribution System Modeling:**
  - Transformer models (suburban and residential areas)
  - Load profiles (light and heavy consumer categories)
  - PV generation data (where applicable)
- These models are used to simulate and analyze system performance under different charging scenarios.

2.2 Simulation Outcomes

- The simulation focuses on three primary impacts of EV charging on the electricity distribution system:
  - **Grid Congestion:** Occurs when aggregate EV load exceeds the installed capacity of distribution transformers or feeders.
  - **Voltage Fluctuations (Steady-State):** Changes in grid voltage during sustained EV charging periods, potentially affecting equipment performance.
  - **Voltage Fluctuations (Short-Term):** Sudden changes in voltage from rapid shifts in charging demand, particularly from fast chargers.
- By integrating EV charging demand curves into the distribution system model, the simulations offer precise insights into where and when the system may become stressed.
- These results guide infrastructure reinforcement planning and the design of smart charging strategies, ensuring that EV deployment progresses without compromising grid reliability.

2.3 Modeling Power Distribution System for EV

- Japan's approach to modeling the impacts of electric vehicle (EV) integration on the power grid extends beyond basic demand forecasting.
- It aims to capture real-world distribution dynamics and thoroughly assess how EV charging affects the electricity distribution system under various conditions.
- Analytical models including charging demand curves for future EV diffusion are developed, and the distribution system is evaluated and analyzed by simulation.

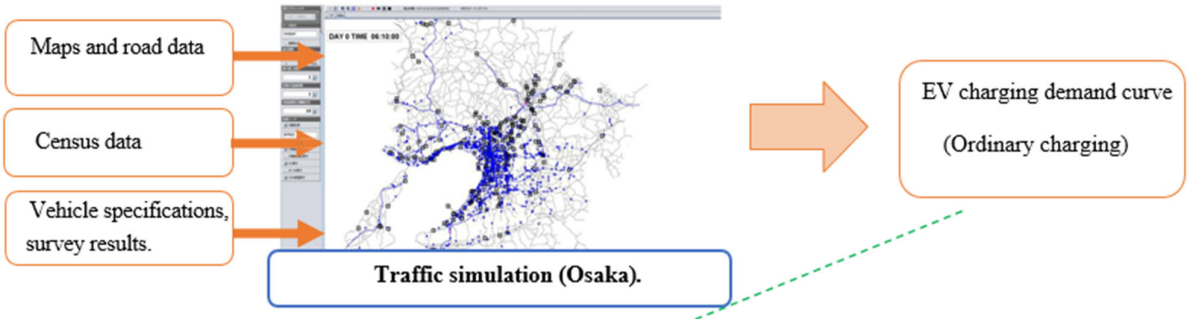


Methodology for Evaluation and Analysis

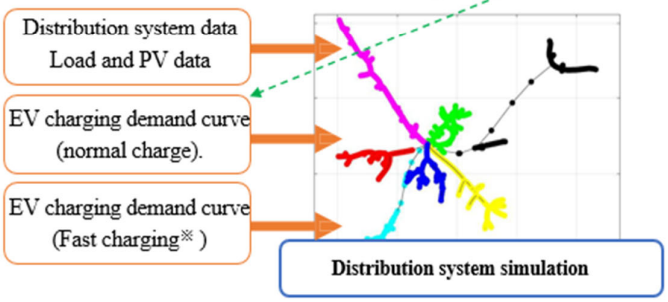
Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

2.3 Modeling Power Distribution System for EV

- (i) EV charging demand curves were created based on the results of a daily EV driving and charging behaviour simulation using traffic simulation for the area of Osaka Prefecture.



(ii) Assess the impact of EV recharging on the distribution system using distribution system simulations with the EV recharging demand curve obtained in (i) as input data.



As for the impact of EV charging on the electricity distribution system,
(i) Grid congestion (excess installed) capacity
(ii) Voltage fluctuations (constant voltage fluctuations)
(iii) Voltage fluctuations (short-term voltage fluctuations).

The charging demand curve for fast charging was prepared using data (sample) provided by the charging companies.

Overall flow of simulation evaluation.

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3. Case Study: Development of Analytical Models for EV Charging Demand

3.1 From Traffic Patterns to Grid Load Analysis

- The simulation process is structured around real-world data and system-level modeling:
- **Create EV Charging Demand Curves**
  - Based on daily travel behavior (from traffic simulations)
  - Includes both regular and fast charging patterns
- **Feed into Distribution System Simulations**
  - Curves are assigned to feeders in D- or H-bank systems
    - **Simulation of feeder performance** with and without SVRs to capture how different voltage regulation strategies manage the impact of clustered EV charging.
    - **Region-specific feeder models** drawn from JST-CREST126, ensuring diversity across urban, suburban, rural, and industrial settings.
  - Load data includes baseline and PV-integrated conditions
- **Evaluate Grid Load and Impacts Analysis**
  - Grid congestion: Exceeds installed capacity
  - Constant voltage deviation: Due to cumulative EV load
  - Instantaneous voltage drops: Linked to fast charging surges

3.1 From Traffic Patterns to Grid Load Analysis

- The simulation highlights how infrastructure in suburban vs. residential areas responds differently to increased EV load, guiding investment and load control strategies.

- By capturing both voltage dynamics and load capacity at fine resolution, the model informs countermeasure planning, including infrastructure reinforcement, placement of voltage regulation equipment, and strategic EV charger deployment to predict loads and maintain grid stability.

3.2 Development of Traffic Simulation Model

- Traffic simulation was conducted to estimate EV charging electricity demand, in order to evaluate its impact on the distribution system.

Parameters for Traffic Simulation (Case Study: Osaka)

classification	parameter	setpoint (e.g. of a function or relation)	Remarks.
EV	Commuter EVs as % of total EVs	25%.	Questionnaire results
	Loaded battery capacity	40 kWh	Assumed specifications for 2030.※
	travelling electric utility charge	7.5 km/kWh	Assumed commercial EV (Nissan LEAF, 2017)
	Initial SOC values on simulation	100%.	Initial value at the start of the simulation (day 1); this initial value does not affect the results as the results from day 3 are used.
	SOC thresholds triggering pathway charging.	20%.	Questionnaire results
(battery) charger	Capacity of ordinary chargers	3 kW	Assumes current mainstream outlet type (3 kW)
	Capacity of fast chargers	50 kW	Rapid charging results not used in this study
	Percentage of business charging units (regular charging) installed.	25%.	Questionnaire results
	Installation rate of home chargers (regular charging)	70%.	Questionnaire results
Other.	Areas covered.	Osaka (metropolitan area) (including a perimeter of 30 km).	Urban areas and surroundings
	Target date	Weekdays, 4 days	In the present study, the results of day 3 will be used.

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.2 Development of Traffic Simulation Model

- From the results of the traffic simulation, time series data on regular electric charging at each residence or business are generated and allocated to consumers on the electricity distribution system as shown in the table below.

Charging Load Allocation to Consumers (Case Study: Osaka)

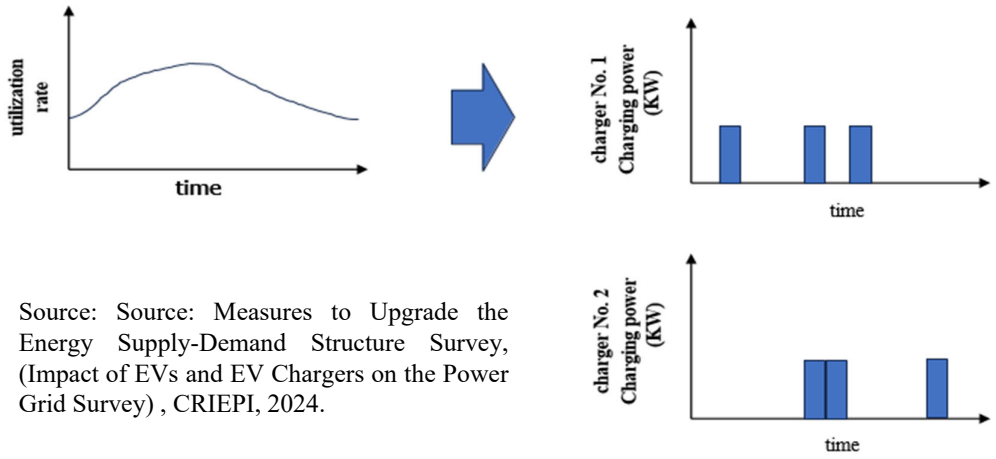
Output data types for traffic simulation.	Customers to be allocated	
	consumer class	number of houses
Residential commuter EV charging load.	low-pressure consumer	Number of low-voltage customer houses× EV penetration ×Proportion of commuter EVs (=25%)
Charging load of non-commuting EVs at residences.		Number of low-voltage customer houses× EV penetration ×Proportion of non-commuting EVs (=75%)
Charging load of commuter EVs at business premises	high-voltage user (Industrial land system).	Number of high-voltage customer houses in industrial area systems. ×Charger penetration in establishments (=25%)
Charging load of non-commuting EVs at business premises	high-voltage user (outside the industrial area system).	Number of high-voltage customer premises outside industrial area systems ×Charger penetration in establishments (=25%)

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.3 EV Demand Curve Modeling Outcomes

- EV fast charging power demand curves are created based on data (samples) provided by charging operators.

EV fast charging power demand curves.



Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

- (Note: To consider the most severe conditions, a separate case is set up where all EV fast chargers operate simultaneously

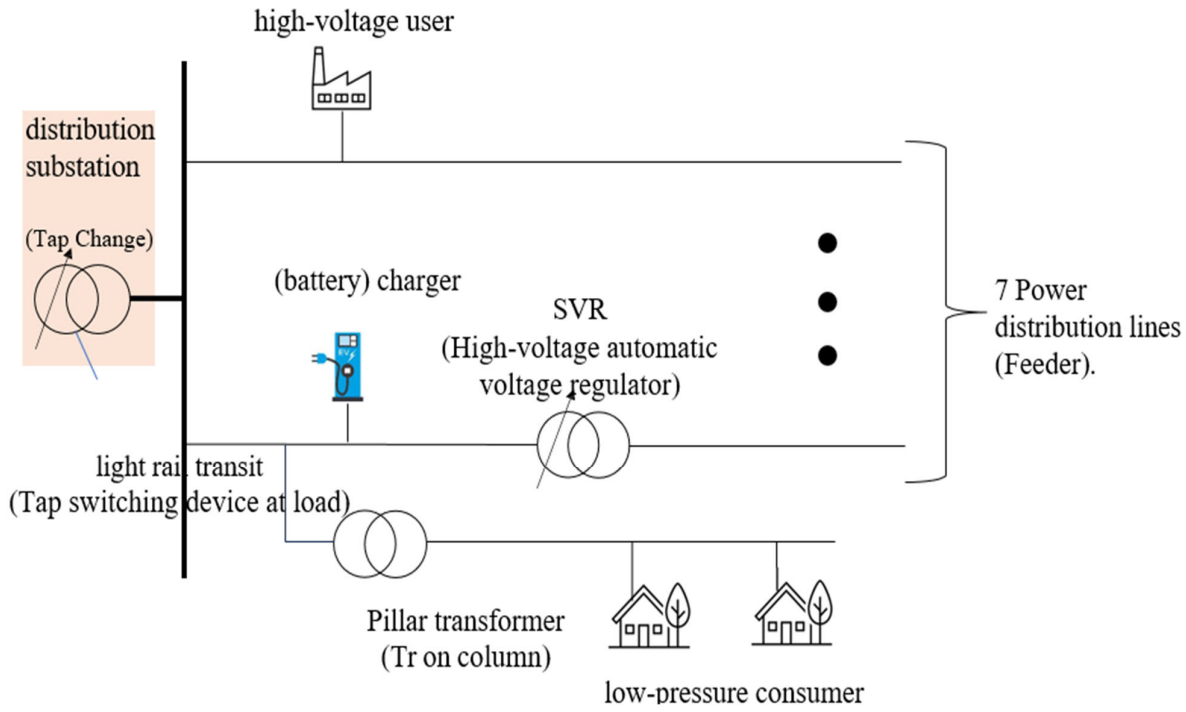
3.4 Development of Distribution System Models

- Japan employs detailed simulation models that incorporate both distribution substations (transformer banks) and distribution feeders (lines).
- This comprehensive framework enables the evaluation of potential overloads not just along feeder lines but also at the substation level.
- In these models, each transformer bank supports multiple feeders, with configurations tailored to reflect regional differences—such as suburban, industrial, and residential areas—ensuring realistic analysis of grid stress caused by diverse EV charging behaviors.
- **The model includes:**
  - **One-bank substation architecture** (a typical three-phase transformer unit).
  - **5 to 7 feeders** per substation, drawn from real-world regional distribution systems.
  - **Feeder variations** include those with and without **automatic voltage regulation (SVRs)** to reflect realistic voltage management diversity.
- This modeling structure enables precise evaluation of localized grid stress due to growing EV charging demand in different geographic settings—urban, suburban, industrial, and rural.

3.4 Development of Distribution System Models

- Key Elements:
  - **Distribution substations (Transformer banks)** and **feeder networks** are modeled using JST-CREST126 datasets.
  - Simulations assess impacts such as:
    - **Grid congestion** (overcapacity)
    - **Voltage fluctuations** (both short- and long-term)
- Models are built using real-world traffic, census, and charger usage data **(Especially a case study for Osaka Prefecture).**
- The distribution system model is built using the **JST-CREST126 distribution line model**, a comprehensive simulation framework jointly developed by:
  - Waseda University's Research Institute for Smart Society Technology Integration
  - The University of Tokyo
  - Tokyo Electric Power Grid Corporation
  - Chubu and Kansai Electric Power Transmission and Distribution Companies

3.4 Development of Distribution System Models



Distribution substations (banks) and feeder networks

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.4 Development of Distribution System Models

- Composition of the D and H Bank Transformer Models
- Two main transformer substation models are used:
  - Transformer D-Bank Model: Designed for suburban and industrial areas, characterized by a wider voltage management margin and fewer low-voltage customers.
  - Transformer H-Bank Model: Reflects residential and mixed-use areas with tighter voltage control requirements, typically more sensitive to voltage fluctuations due to higher customer density.
  - Detailed Representation of Grid Segments: to reflect Japan's regional diversity and voltage stability needs, two transformer bank models are used:

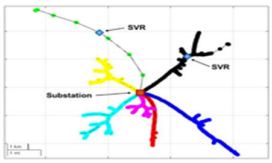
Feature	Transformer D-Bank (Suburban/Industrial)	Transformer H-Bank (Residential)
Use Case	Suburban and light industrial zones	Urban residential and mixed-use zones
Voltage Margin	Wide – Tolerates greater fluctuations	Narrow – Sensitive to voltage instability
Customer Load	Fewer low-voltage users	High density of low-voltage households
EV Implications	Better suited to absorb moderate EV charging	Prone to voltage stress from peak residential EV load

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.5 Case Study: Osaka Prefecture

- Feeder-Level Allocation of Fast Charging Infrastructure
- This case study demonstrates how to determine the appropriate number and distribution of fast EV chargers on individual distribution feeders using load capacity assumptions and grid simulation principles.
- The process assumes a fixed fast charger output and models its spatial deployment to evaluate feeder-level impacts.

The D-bank model is mainly aimed at suburban areas. Bank D has fewer low-voltage customer households than Bank H.



Transformer D-bank model

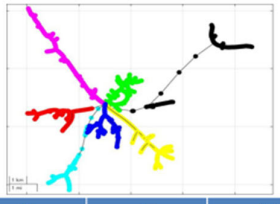
	F1	F2	F3	F4	F5	F6	F7
classification	farming and mountain villages	farming and mountain villages	(manufacturing) industry	(manufacturing) industry	(manufacturing) industry	farming and mountain villages	farming and mountain villages
Low-voltage Number of demanding households	1007	407	177	126	549	261	215
High-voltage Number of demanding households	15	9	5	3	24	9	10
length	7.58 km	4.56 km	4.01 km	8.54 km	3.89 km	2.26 km	7.35 km
SVR's. number of large objects such as cars, computers, etc.	1	0	0	1	0	0	0

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.5 Case Study: Osaka Prefecture

- These models are based on a previous NEDO R&D initiative (“Next Generation for Mass Introduction of Renewable Energy,” Project P19002), which consolidated multiple JST-CREST126 feeder models into realistic one-bank substation configurations.

The H-banking model is mainly aimed at residential areas.
More low-voltage customer premises and longer distribution lines than D-banks



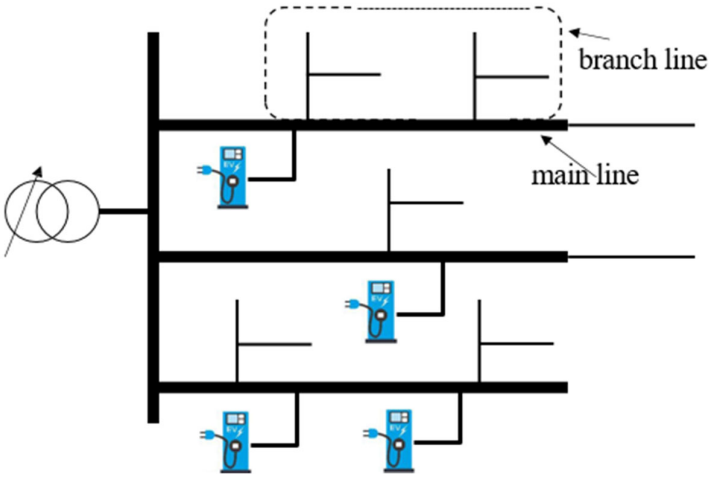
Transformer H-bank model

	F1	F2	F3	F4	F5	F6	F7
classification	housing	housing	(manufacturing) industry	housing	housing	housing	(manufacturing) industry
Low-voltage Number of demanding households	659	712	622	2049	1072	1718	918
High-voltage Number of demanding households	11	7	12	24	5	16	13
length	9.56 km	7.53 km	5.21 km	6.44 km	7.34 km	9.79 km	6.52 km
SVR's. number of large objects such as cars, computers, etc.	0	0	0	0	0	1	0

Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

3.5 Case Study: Osaka Prefecture

- The output of the fast charger was set at **90 kW**.
  - **The required number of fast chargers per feeder** is calculated based on the total allocated charging load.
  - The number of fast chargers per feeder based on output is calculated.
  - The chargers are then **geographically assigned along the main distribution lines** within each Transformer bank to reflect realistic siting as shown in the diagram below.
    - For Example: If the amount of fast charging introduced to one feeder is 2,000 kW and the output power of the fast charger is 90 kW then Number of fast chargers distributed within one feeder: 22 units
    - → *Number of chargers = Total feeder charging load ÷ 90 kW*



Source: Source: Measures to Upgrade the Energy Supply-Demand Structure Survey, (Impact of EVs and EV Chargers on the Power Grid Survey) , CRIEPI, 2024.

Presentation Material 2- 12

Activity 2-4-1 Benchmark on the Connection Guidelines of IRVE to the Distribution System Including Case Study in Japan Part (1)

Benchmark on the Connection Guidelines of IRVE to the Distribution System Including Case Study in Japan Part (1)

Activity 2-4-1

JICA Expert Team

September 2024

Japan International Cooperation Agency
Tokyo Electric Power Services Company, Ltd.

Agenda in this Presentation

Activities	Contents	JICA expert	STEG	Time schedule
2-1	**Review technology options (Batteries, IRVE (Infrastructures de recharge pour véhicule électrique), V2X, charging connectors etc.) for the penetration of EV**	-	-	-
2-1-1	Lecture and workshop on the technologies related to EV (including smart charging, V2X, Charging Management System)	✓		2nd
2-2-2	Introduction of case studies in Japan	✓		2nd
2-2	**Investigate issues on grid connection of IRVE and propose countermeasures for the issues.**	-	-	-
2-2-1	Benchmark on the impact on the power distribution system including case study in Japan	✓		2nd
2-2-2	Lecture on simulation methods for the impact of EVs on the electric power distribution system	✓		3rd
2-2-3	Identify the issues on the power distribution system in the connections of IRVE in Tunisia	(✓)	✓	2nd-3rd
2-2-4	Discussion on the issues and countermeasures	✓	✓	3rd
2-3	**Propose demand forecast based on a scenario of EV penetration**	-	-	-
2-3-1	Share the report of EV penetration scenario in Tunisia		✓	1st
2-3-2	Create/Assume a scenario of EV penetration	(✓)	✓	-3rd
2-3-3	Lecture on the methodology for electricity demand forecast of EV in Japan	✓		3rd
2-3-4	Provide the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration		✓	3rd
2-3-5	Review the methodology created by STEG for electricity demand forecast based on a scenario of EV penetration	✓		4th-5th
2-3-6	Report the comments to STEG	✓		5th
2-3-7	Discussion on the comments	✓	✓	5th
2-3-8	Improve the methodology		✓	5th-
2-4	**Capacity Building for design and inspection of IRVE**	-	-	-
2-4-1	Benchmark on the connection guidelines of IRVE to the distribution system including case study in Japan	✓		2nd
2-4-2	Identify the items to be included in the guideline	(✓)	✓	2nd-3rd
2-4-3	Discussion on the items and contents of the guideline	✓	✓	3rd
2-4-4	Draft the connection guideline of IRVE to the distribution system		✓	3rd-4th
2-4-5	Review the guideline	✓		3rd-4th
2-4-6	Report the comments to STEG	✓		4th
2-4-7	Discussion on the comments	✓	✓	4th
2-4-8	Finalize the guideline		✓	4th-

11. Wheeling Service Provision in Japan

11.1 Wheeling Service: Requirements for Connection

- The method of electricity supply is specified in the Wheeling Supply Agreement based on the Electricity Business Act.
- Due to an increase in non-principle needs, such as the supply of EV chargers, the "special exception zone" was approved by METI, allowing two separate contracts at one service point.

- [In the case of TEPCO]

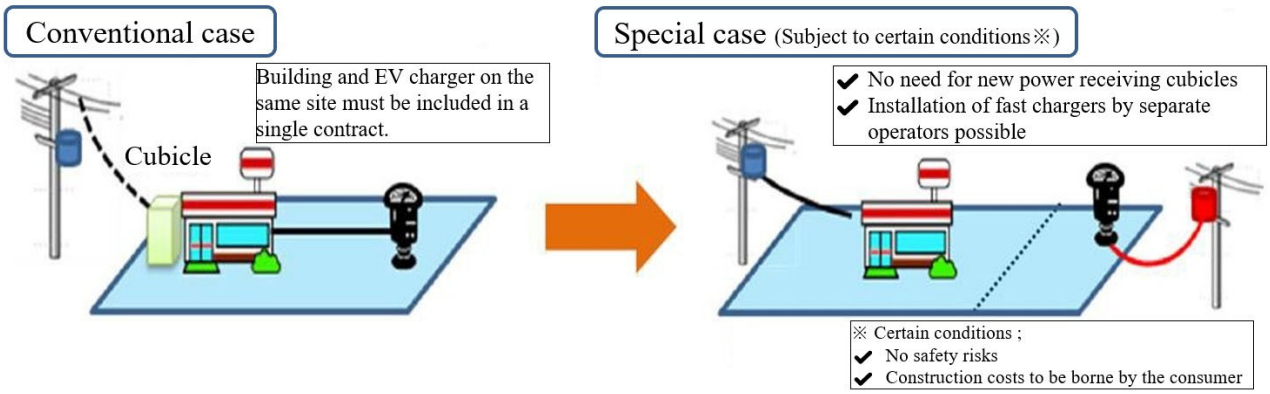
<Conditions for special exception zones>

➢ When facilities necessary for any of the following three conditions are newly installed, the building or part of the building in which such facilities are installed may be designated as a special exception zone.

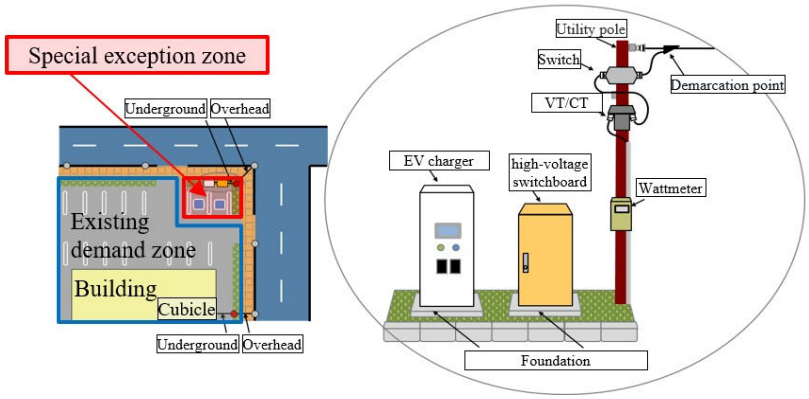
a. Disaster prevention (measures to prevent damage from disasters)
b. Environment (measures to reduce greenhouse gas emissions)
c. Rationalization of equipment (measures to rationalize the installation and operation of electrical equipment)

11.2 Wheeling Service: Example of Special Exception Zone

■ Overview



■ Example of special zones in high voltage supply



Two connections to the building and to the EV charger can be made in the same compartment.

For safety reasons, it is important that the two extension cables are not mixed up (to avoid the risk of electric shock).

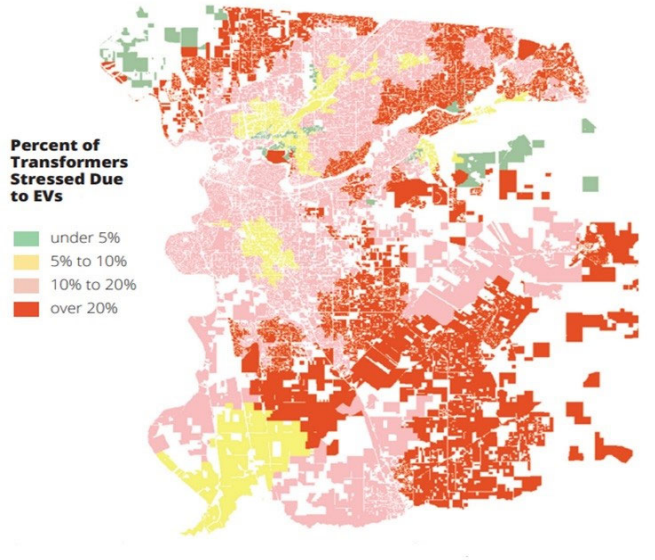
Source: CHAdeMO Association: Guidance on the installation and operation of quick chargers for electric vehicles, 2024

12. Case Studies: Impact of IRVE Connection on Power Distribution Systems

12.1 Impact of IRVE Charging on Transformer Reliability

- The case study investigates the IREV impact on Sacramento Municipal Utility District "SMUD" transformers
- **Transformer Replacement Needs:**
  - Up to 17% (12,000) of SMUD's service transformers may require replacement due to overloads.
  - The estimated cost of replacing each transformer is $7,400.
  - By 2030, the costs related to transformer replacement are projected to be about $100 per EV

FIGURE 3: EV IMPACT ON TRANSFORMERS IN THE SACRAMENTO MUNICIPAL UTILITY DISTRICT SERVICE TERRITORY THROUGH 2030



Source: Smart Electric Power Alliance, Black & Veatch, and SMUD, 2017

12.1 Impact of IRVE Charging on Transformer Reliability

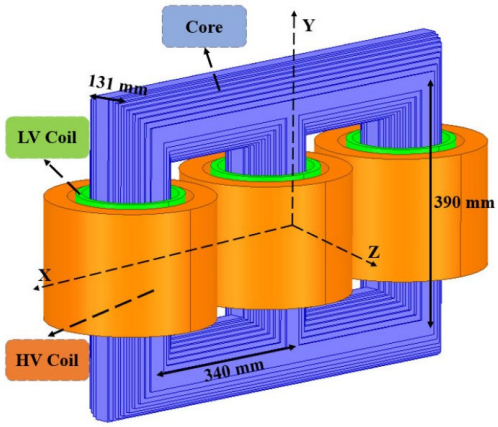
- **Impact of IRVE Charging:**
  - The study indicates that 17% of transformers are likely to be stressed due to increased EV charging, particularly from uncontrolled charging.
  - Managed EV charging is proposed as a solution to reduce transformer stress and delay the need for upgrades, provided the cost of communication infrastructure is manageable.
  - Implementing rate-based incentives for midday EV charging could help absorb excess photovoltaic (PV) generation and ease grid demand.
- **Cost Efficiency Measures:**
  - The Sacramento Municipal Utility District estimates that adopting one-way smart charging could cut grid upgrade expenses by over 70%.

12.1 Impact of IRVE Charging on Transformer Reliability

■ Impact of IRVE Overloads on Distribution Transformer Lifespan

- The study examines the impact of overloading on a 100-kVA distribution transformer due to electric vehicle (EV) charging.
- Overloading raises the Hot-Spot Temperature (HST), leading to insulation degradation and a shortened transformer lifespan.
- Using multi-physics analysis and simulations (Ansys Maxwell and Thermal modules), the study demonstrates how higher loading conditions cause significant temperature rises, particularly in the low-voltage windings, accelerating transformer aging.
- Overload Impact: Overloading increases power losses and HST, reducing transformer lifespan.
- Lifetime Degradation: Transformers under heavy loads age faster, with aging acceleration factors increasing exponentially at higher HSTs.

12.1.1 Impact of IRVE Overloads on Transformer Lifespan



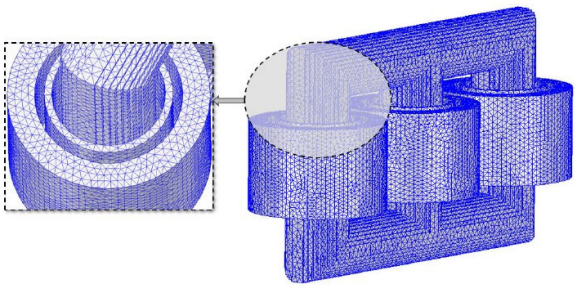
Topology and dimensions of the distribution transformer under investigation.

Main parameters of the distribution

Parameter	Value
Apparent Power	100 KVA
HV Rating	33 KVA
LV Rating	0.4 KV
Frequency	60 Hz
Type of Cooling	ONAN

Table. Loss components in different loading

Load Percentage	100%	110%	125%	150%
Load Loss (W)	1905	2156	2447	3106
Volumetric Core Loss Density (W/m^3)	5603	5603	5603	5603
HV Winding Loss Density (W/m^3)	26416	29916	33916	43083
LV Winding Loss Density (W/m^3)	75476	85476	96904	123095



Finite element meshes of the distribution transformer model.

Source: Impact of Electric Vehicle Charging on Power Distribution Systems: A Case Study of the Grid in Western Kentucky," P. Roy et al., IEEE Access, 2023.

12.1.1 Impact of IRVE Overloads on Transformer Lifespan

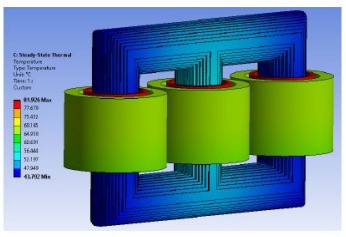
- **Recommendations**:
  - Upgrading smaller transformers (5-10 kVA) or implementing EV charging rate limits is advised. Time-of-use schemes can help distribute EV charging to avoid transformer overloading.
  - This concise summary highlights the key impacts of overloading and offers practical solutions for extending transformer lifespan in light of increased EV charging demands.

Corresponding lifetime reduction in different loading

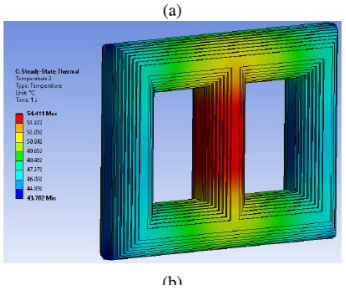
Load Percentage	100%	110%	125%	150%
HST (C)	81.9	87.4%	93.8%	108.3%
Per Unit Life	1	0.5246	0.2538	0.0536
Aging acceleration Factor	1	1.906	3.94	18.65

Source: Impact of Electric Vehicle Charging on Power Distribution Systems: A Case Study of the Grid in Western Kentucky," P. Roy et al., IEEE Access, 2023.

12.1.1 Impact of IRVE Overloads on Transformer Lifespan

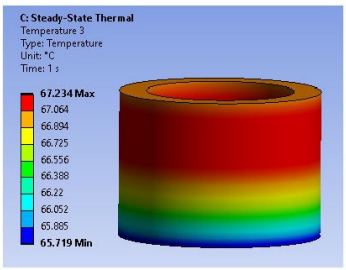


(a)

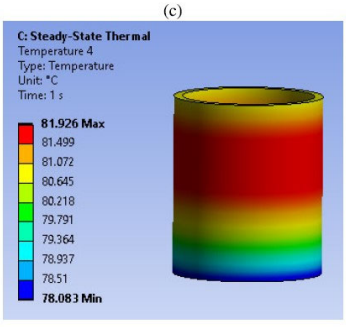


(b)

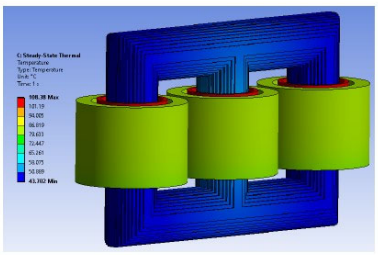
Temperature distribution of the transformer
a) Whole geometry
b) Magnetic core,
c) HV windings and
d) LV windings at 100% loading.



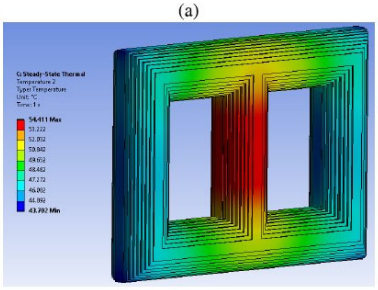
(c)



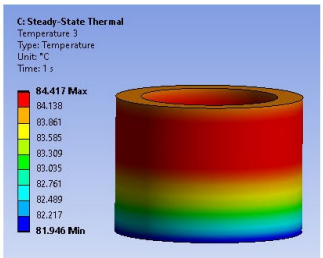
(d)



(a)

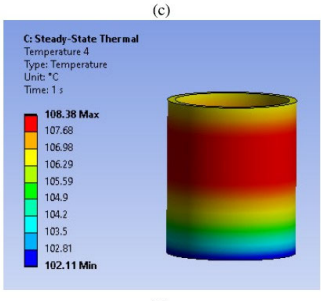


(b)



(c)

Temperature distribution of the transformer
a) Overall geometry
b) Magnetic core
c) HV winding
d) LV winding at 150% loading.



(d)

Source: Impact of Electric Vehicle Charging on Power Distribution Systems: A Case Study of the Grid in Western Kentucky," P. Roy et al., IEEE Access, 2023.

12.2 Impact of IRVE on Harmonic Emissions and PQ

- **This study examines the Harmonics "Waveform Distortion" due the electric IRVE charging influences in power grids, particularly focusing on current harmonic emissions.**
- **The emission levels depend on:**
  - Charger circuit design
  - Power levels
  - Supply voltage distortion
  - Network impedance.
- **Harmonic Emissions**
  - Diode Rectifiers: Older rectifiers emit high current harmonics, but advancements in charger design and control have reduced these emissions.
  - Charging Cycle: The charging process includes constant current (CC) and constant voltage (CV) stages. Harmonic distortion is lower during CC but increases during CV.
  - Charger Variability: There is significant variation in total harmonic distortion (THDi) and individual harmonics among different EV chargers.
  - Slow Chargers: The diversity in EVs and their states of charge (SOC) affects harmonic emissions, resulting in a cancellation effect when aggregated.
  - Fast Chargers: These are easier to manage due to their fixed locations, but variability in EVs and SOCs still introduces uncertainty in harmonic studies.

12.2 Impact of IRVE on Harmonic Emissions and PQ

- This study examines the **Harmonics "Waveform Distortion"** due the electric IRVE charging influences in power grids in Sweden, particularly focusing on current harmonic emissions.
- **Types of Harmonic Studies :**
  - Deterministic Studies: Focus on precise modeling of charger behavior, cancellation effects, and the impact of background voltage on harmonic emissions.
  - Stochastic Studies: Incorporate uncertainties like EV diversity, SOC diversity, and background voltage variations for more realistic results.
- **The harmonics emission levels depend on:**
  - Charger circuit design
  - Power levels
  - Supply voltage distortion
  - Network impedance.