12.2 Impact of IRVE on Harmonic Emissions and PQ

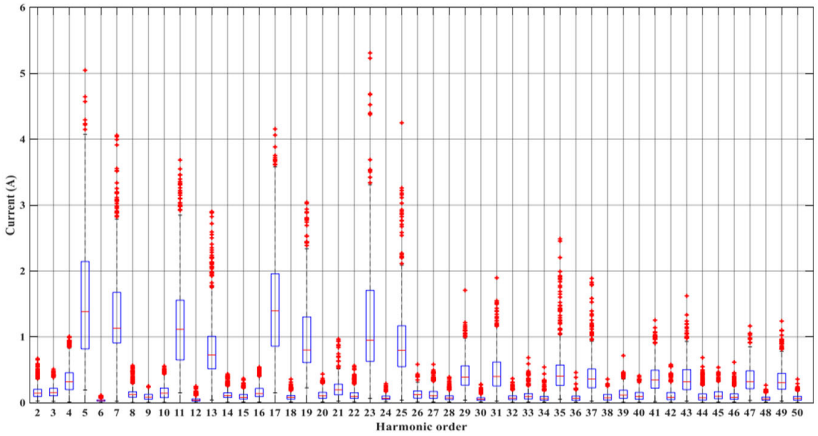
■ Harmonic Emissions

- 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

■ Case Study Details

- **Location:** The study focuses on a 160 kW EV fast charger in a winter car testing centre in North Sweden.
- **Methodology:** Measurements and waveform snapshots were taken over a month, analysing 96 charging cycles with varying power levels and durations.



Boxplot of current harmonic emission.

Source: Impact of Electric Vehicle Charging on the Power Grid," S. Sudha Letha et al., 2021.

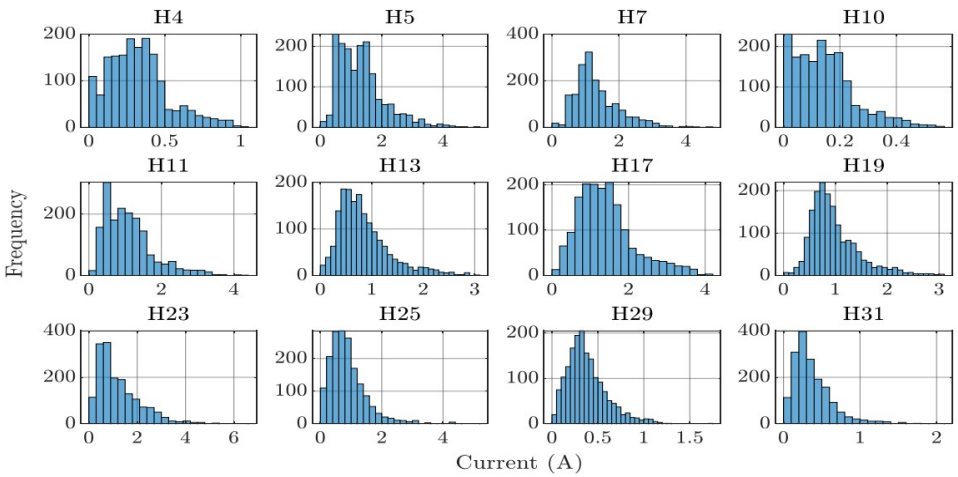
- **Findings:** Higher harmonic values were observed for certain orders (e.g., 5th, 7th, 11th). Notably, even harmonics (4th, 10th) showed high emissions, likely due to DC current affecting transformer saturation.

12.2 Impact of IRVE on Harmonic Emissions and PQ

- Impact on Power Quality: Harmonics, inter-harmonics, and supra-harmonics present during EV charging affect power quality, especially in low and medium voltage networks.
- Aggregation Effects: The study highlights the need for unified measurements and standardization in supra-harmonic range studies due to their significant impact despite low magnitudes.
- Stochastic Modelling: Probability Density Functions (PDF) of individual harmonics are critical for stochastic models and accurate Monte Carlo simulations.
- Voltage Dips: Shallow voltage dips, particularly with phase angle jumps, significantly impact EV charging and battery life, with effects varying based on network impedance and cable capacitance.

12.2 Impact of IRVE on Harmonic Emissions and PQ

- Addressing uncertainties in harmonic studies for EV chargers is essential for accurate assessments.
- Understanding harmonic behaviour during different charging stages and cycles is crucial for mitigating power quality issues.

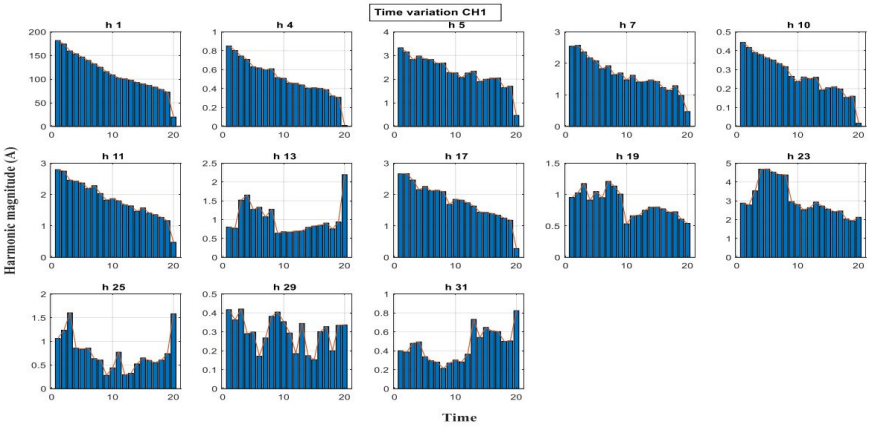


Harmonic current emission histogram for dominating harmonic orders.

Source: Impact of Electric Vehicle Charging on the Power Grid," S. Sudha Letha et al., 2021.

12.2 Impact of IRVE on Harmonic Emissions and PQ

- Stochastic approaches provide realistic assessments of harmonic emissions and their impacts on power grids, aiding in the development of effective mitigation strategies for waveform distortion due to IRVE.
- Individual harmonic orders exhibit varying patterns during the charging cycle. As shown in Fig. some harmonics, such as the 5th and 7th, align with the fundamental frequency's pattern."



Time variation of individual harmonic orders during one charging cycle.

Source: Impact of Electric Vehicle Charging on the Power Grid," S. Sudha Letha et al., 2021.

12.3 Impact of IRVE on Voltage Profiles and "PAR"

- The case study investigates the impact of electric (IRVE) charging loads on Voltage Profiles and Peak to Average Ratio (PAR) of distribution systems in Italy.
- Focusing on various factors such as voltage profile, maximum voltage deviation, Peak-to-Average Ratio (PAR) of active power, peak loads, and transformer loading. The analysis is based on realistic grid data from Italy and considers both summer and winter seasons.

- **EV Load Penetration and Distribution Network:**
- The study analysed four case studies with different EV load penetration levels, ranging from low to high.
- Increased EV load penetration leads to higher transformer loading and PAR, indicating greater variability between peak and average power demands. This trend suggests that the distribution network may struggle to accommodate high levels of EV penetration without further development.

12.3 Impact of IRVE on Voltage Profiles and "PAR"

■ Impact on Peak to Average Ratio "PAR" :

- The Peak-to-Average Ratio (PAR) measures the variability of power demand, comparing peak demand to average demand. The study found that higher EV load penetration increases PAR, reflecting greater fluctuations in power demand. A 45% EV penetration led to about a 1% increase in maximum voltage deviation compared to no EV penetration.
- The distribution network studied is deemed ready to handle safe EV load penetration up to 2026 with its current infrastructure. However, as EV load penetration increases, the system will need enhancements, especially if penetration exceeds 40%. The study emphasizes the importance of managing PAR and voltage deviations to maintain grid reliability.

V Results Obtained in Case I

	no EVs		11.3% EVs		35% EVs		45% EVs	
Season	summer	winter	summer	winter	summer	winter	summer	winter
Max. % trafo load	46.22	47.20	54.25	56.07	72.46	75.51	80.26	83.87
Min. % trafo load	32.81	31.12	35.27	35.30	40.46	44.13	42.66	47.88
Peak power [MW]	18.48	18.88	21.70	22.43	28.98	30.20	32.10	33.55
Average power [MW]	16.40	16.05	18.57	18.63	23.16	24.10	25.11	26.43
PAR (power)	1.13	1.18	1.17	1.20	1.25	1.25	1.28	1.27
Max. voltage deviation [%]	0.49	0.58	0.70	0.75	1.17	1.13	1.37	1.30

VI Results Obtained in Case II.

Year	2020				2023				2026			
EV	0%		35%		0%		47%		0%		50%	
Season	S	W	S	W	S	W	S	W	S	W	S	W
Max. % trafo load	46.22	47.20	72.46	75.51	48.52	49.56	84.16	87.94	48.52	50.95	87.90	91.91
Min. % trafo load	32.81	31.12	40.46	44.13	34.44	32.66	44.74	50.20	35.40	33.58	46.37	52.35
Peak power [MW]	18.49	18.88	28.98	30.21	19.41	19.82	33.66	35.17	19.95	20.38	35.16	36.76
Average power [MW]	16.40	16.05	23.16	24.11	17.22	16.85	26.33	27.71	17.70	17.32	27.41	28.90
PAR (power)	1.13	1.18	1.25	1.25	1.13	1.18	1.28	1.30	1.13	1.18	1.29	1.28
Max. voltage deviation [%]	0.49	0.58	1.17	1.13	0.52	0.61	1.44	1.36	0.53	0.62	1.52	1.43

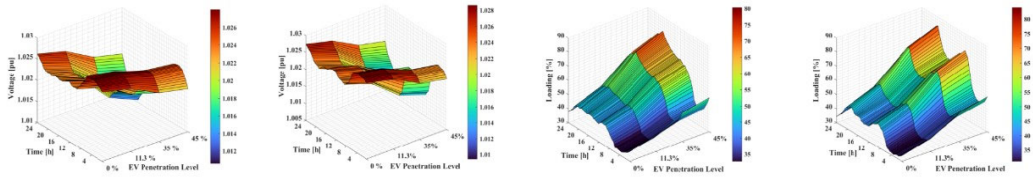
Source: DOI: 10.1109/EEEIC/ICPSEurope51590.2021.9584782.

12.3 Impact of IRVE on Voltage Profiles and "PAR"

■ Impact on Voltage and Transformer Loading:

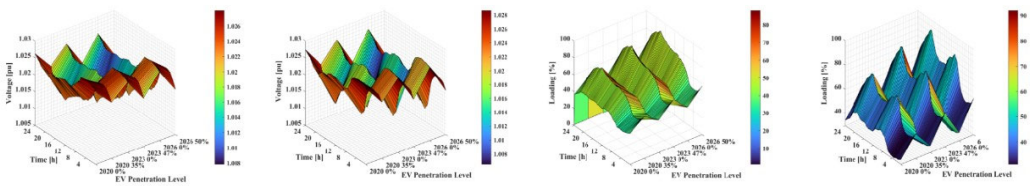
- The study observed a slight voltage drop at medium voltage (MV) nodes, but the voltage remained within acceptable limits.
- During peak hours, transformer loading reached up to 83.87% in the worst-case scenario with 45% EV penetration during winter. The grid can handle up to approximately 40% EV penetration without needing major upgrades. Above this level, transformer replacement may be necessary.

Case I



(a) Voltage profile (summer). (b) Voltage profile (winter). (c) Trafo loading (summer). (d) Trafo loading (winter).

Case II



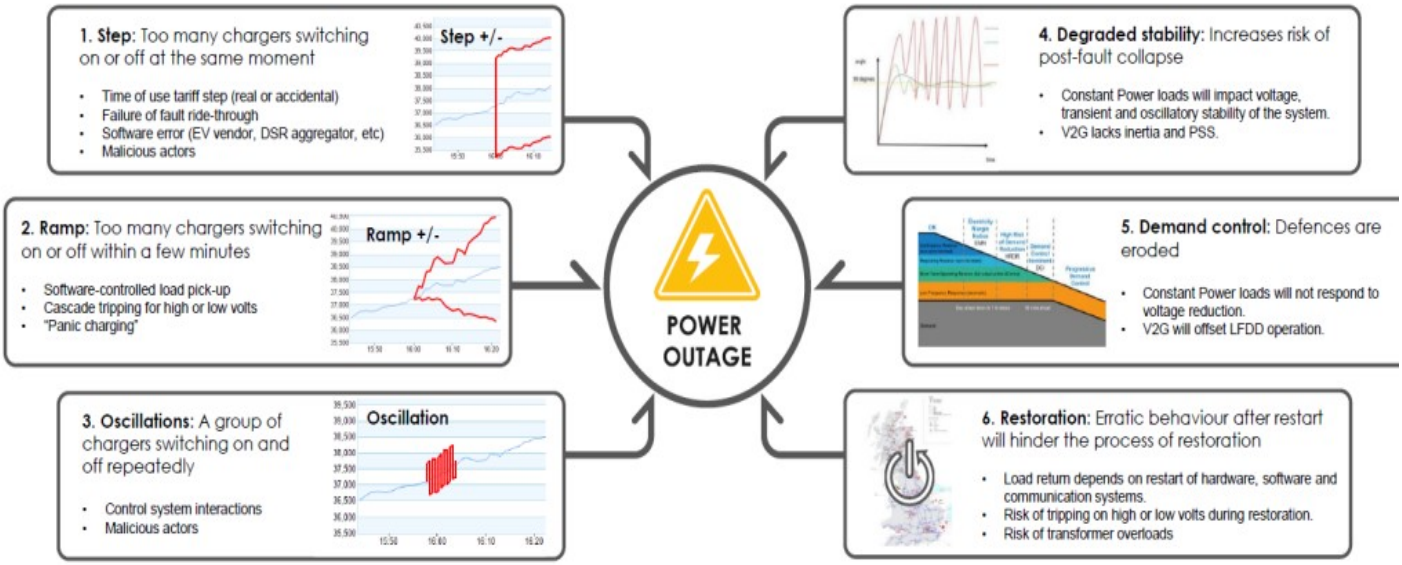
(e) Voltage profile (summer). (f) Voltage profile (winter). (g) Trafo loading (summer). (h) Trafo loading (winter).

Case III

Source: DOI: 10.1109/EEEIC/ICPSEurope51590.2021.9584782.

12.4 Impact of IRVE on "PBS" Grid Reliability

- The case study investigates the knowledge gaps regarding EV charging behaviours contribute to uncertainty in planning and understanding the electrical impacts these devices may have on the Bulk Power System "PBS" in the UK.

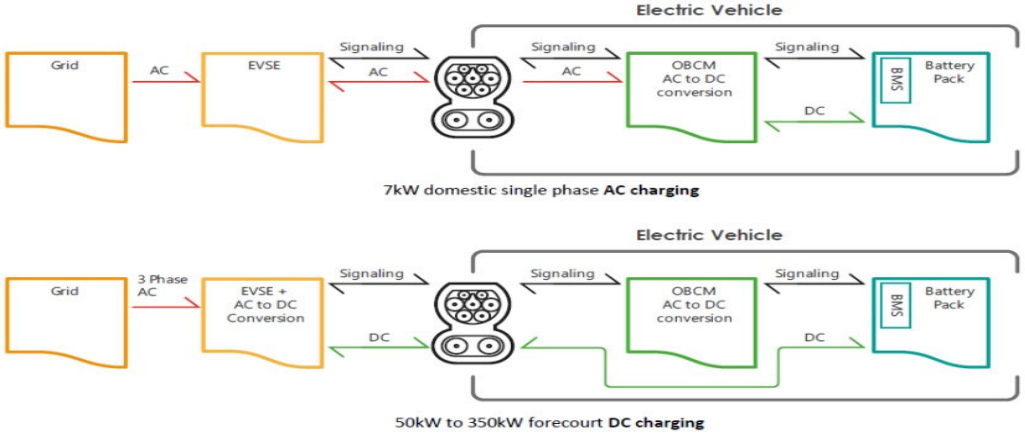


Source: Sygensys

Source: Potential Bulk Power System Impact of Electric Vehicle Charger," NERC, "Grid Impact of Electric Vehicle Chargers: Preliminary Findings and Recommendations," 2024.

12.4 Impact of IRVE on "PBS" Grid Reliability

- A significant finding from the growth projection reports in the UK is the effect of charging infrastructure on the capacity requirements of distribution and transmission systems.
  - ➢ Infrastructure Impact: The impact of IRVE charging on BPS is highly dependent on the charging capacity. DC chargers, capable of up to 350 kW or more, significantly affect the BPS.
  - ➢ Load Considerations: EV adoption increases, the added load from IRVE charging will stress the BPS. Larger charging stations, especially those with high-capacity chargers, may need direct connections to the BPS.



Source: Sygensys

Difference in Capacity Needs for AC and DC Charging

Source: Potential Bulk Power System Impact of Electric Vehicle Charger," NERC, "Grid Impact of Electric Vehicle Chargers: Preliminary Findings and Recommendations," 2024.

12.5 Power Loss Reduction & Optimizing IRVE Planning

- The case study investigates the IRVE Planning & Minimizing Power Loss in Distribution Network
- This study examines the planning and optimization of IRVE and power networks with a focus on New York's traffic and distribution network data.
- **Model Overview:**

➢ The study integrates charging stations as both traffic service and common electric facilities. A multi-objective model is developed to maximize captured traffic flow and minimize power loss in distribution networks. Using a 33-node distribution system and a 25-node traffic network, the research identifies optimal charging locations by simulating charging demand with traffic flows and considering constraints like maximum EV travel distance.

- **Methodology:**

➢ A fuzzy multi-objective model and genetic algorithm (GA) optimize the placement of charging stations.

➢ Objectives: Maximize traffic flow capture and minimize power loss.

12.5 Power Loss Reduction & Optimizing IRVE Planning

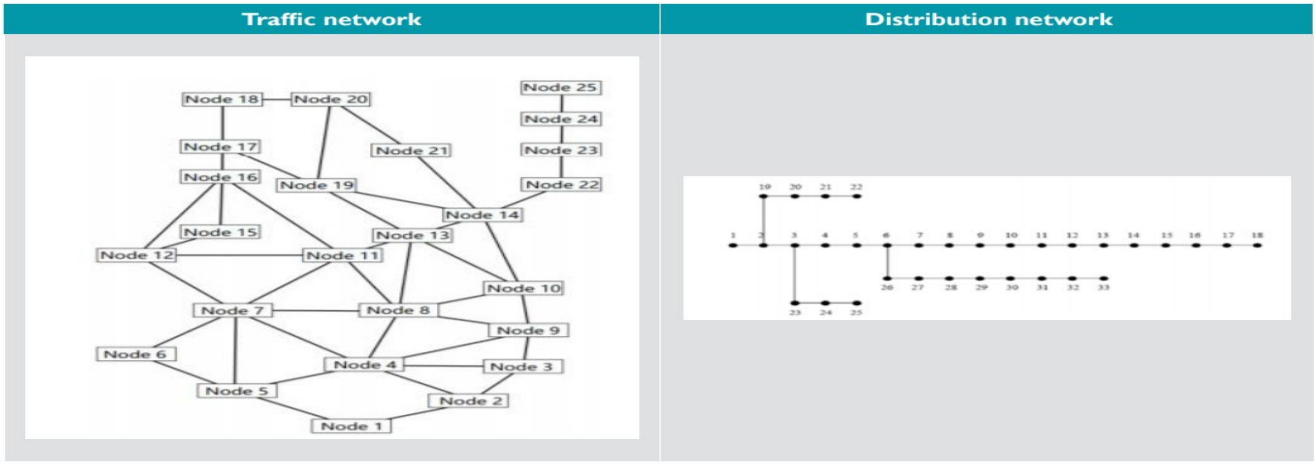
- **Key Electric Assumptions & Distribution Network:**

➢ Power at each node and power flow on each branch must not exceed distribution network limits to prevent grid damage.

➢ The capacity of charging stations should meet or exceed the maximum load requirement.

➢ Only one type of charging station (normal or fast) can be built at a node.

➢ Urban land constraints limit the number of charging poles to avoid idle resources.



Source: Electric Vehicle Charging Infrastructure and Impacts on Distribution Network," Greening the Grid (GTG)- Renewable Integration and Sustainable Energy (RISE) Initiative, a partnership between USAID and Ministry of Power, GOI, 2020.

12.5 Power Loss Reduction & Optimizing IRVE Planning

- **Charging Behavior:**
  - Fast charging stations (FCS) operate during peak hours, following a first-come, first-served (FCFS) rule.
  - The size of FCS is determined by mean arrival rate and service demand, aiming to minimize construction costs and meet charging demand.
- **Results and Inferences:**
  - High-capacity charging stations should be placed at the front end of system feeders to minimize power loss.
  - To balance traffic flow capture and power loss, charging stations are mainly located in transport hubs with higher node weight.
  - Managed EV charging and rate-based incentives for midday charging can reduce transformer stress and defer upgrades.
  - One-way smart charging could potentially reduce grid upgrade expenses by over 70%.
- **Conclusion:**
  - The study identifies optimal charging station locations and capacities, ensuring minimal power loss and efficient traffic service. It highlights the importance of integrating charging infrastructure into the existing power network while considering electric constraints and optimizing grid performance.

13. Case Studies: Mitigation Strategies for PQ in Distribution Systems

13.1 Mitigation for PQ Imbalance and Transformer Stress

■ Voltage Fluctuations Impact and Mitigation:

➢ Uneven voltage magnitudes and phase angles in 3-phase system cause voltage imbalances, which can be mitigated through phase reconfiguration. This approach, evaluated for its cost-effectiveness, uses time-of-use tariffs to reduce imbalance impacts. Managing EV charging and discharging can also alleviate voltage imbalance by optimizing connection points, power rates, and charging status. Developing a control mechanism for smart charging and a communication system for data exchange can standardize voltage profiles and smooth load profiles. Voltage regulators, energy storage, feeder capacitors, and D-STATCOMs are used to improve power quality.

■ Harmonics Impact and Mitigation:

➢ Harmonics, caused by nonlinear devices such as EV chargers and inverters, lead to waveform distortions. The impact of harmonics is more pronounced with fast EV charging and high penetration rates. Mitigation techniques include power filters, modulation techniques (e.g., SPWM, SVPWM), and the use of shunt active power filters. EVs may also act as harmonic compensators and participate in ancillary services. To address harmonics, both passive and active filters are used, alongside advanced inverter control mechanisms. Solving harmonic power flow problems involves coupled and decoupled approaches, with infrastructure improvements like increased transformer ratings suggested to handle EV charging impacts.

■ .

13.1 Mitigation for PQ Imbalance and Transformer Stress

■ Transformer Impacts and Mitigation:

➢ The future of EVs may benefit from adopting solid-state transformers (SSTs) due to their compatibility with AC/DC grids and dynamic control capabilities. SSTs enhance communication, protection, and power quality. However, upgrading transformers to meet increased demand is often impractical. Instead, demand-side control can delay EV charging, and encouraging flexible EV demand helps mitigate transformer overloading. Increased EV penetration can lead to transformer degradation, characterized by load loss, increased temperature, and reduced lifespan.

13.2 Mitigating Strategies for Transformer Overloads

- **Strategies for Voltage Regulation to Mitigate Distribution Transformer Overloads Caused by IRVE**:
- **Automated and Controllable Tap Changers:** On Load Tap Changer (OLTC) transformers can accommodate 100% of EVs at normal/slow charging rates, with an upgrade cost.
- **Capacitor Banks:** improve voltage profiles, while large-scale capacitor bank installations can cause resonance due to harmonics and switching transients, leading to high voltages or currents.
- **Static Compensators (STATCOM):** Mitigate voltage dips but add to augmentation costs.
- **Decentralized Battery Storage Systems:** Serve as local power sources when coupled with charging infrastructure.
- **The potential of STATCOMs and decentralized Battery-Based Storage systems:** is managing voltage fluctuations and enhancing the stability of the distribution network.

13.2 Mitigating Strategies for Transformer Overloads

- A study by Dublin Institute of Technology (DIT) examined the effects of substantial IRVE loads on an Irish urban distribution network and evaluated the efficacy of STATCOM devices in mitigating voltage magnitude and unbalance issues.

➢ EVs are disconnected from the grid during office hours (9:00 am to 5:00 pm) and charged outside these hours.

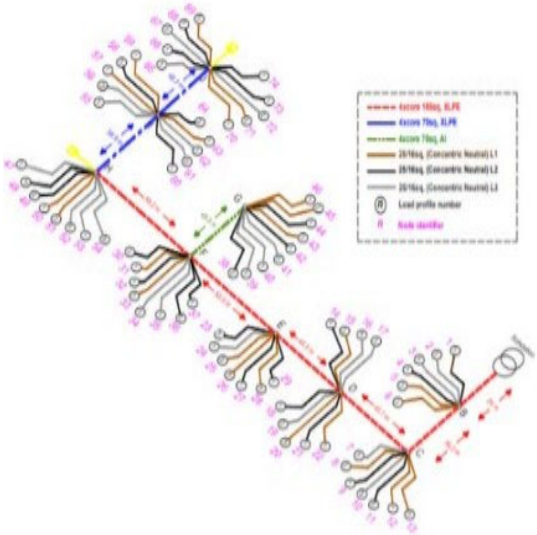
➢ Realistic EV battery load profiles were designed based on typical passenger car travel requirements.

➢ Battery capacities considered: 20 kWh for standard EVs, 40 kWh for advanced EVs, and 200-300 kWh for electric buses.

Table: Overview of the model

Details	Particulars
Platform	DIgSILENT power factory
No of customers	74, and connected from a 10/0.4 kV transformer in a radial network topology
Voltage deviation limits	+-10% of nominal value
Residential load modelling	Household load demand profile obtained from DSO
STATCOM placement	Connected at several pillars / locations to measure voltage profile without and with STATCOM placement

Source: Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level



Distribution System analysis for EV Loading

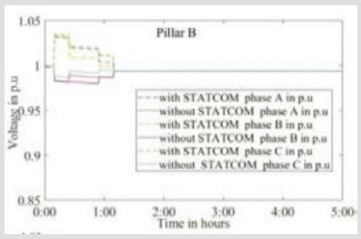
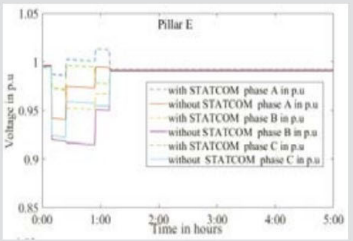
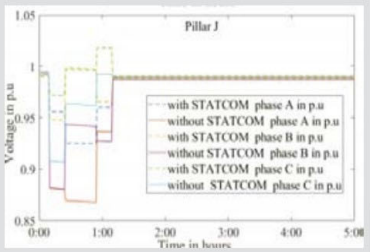
Source: Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level

Source: Electric Vehicle Charging Infrastructure and Impacts on Distribution Network," Greening the Grid (GTG)- Renewable Integration and Sustainable Energy (RISE) Initiative, a partnership between USAID and Ministry of Power, GOI, 2020.

13.2 Mitigating Strategies for Transformer Overloads

■ Study Insights

- ➢ Proximity to MV Grid: EVs connected close to the medium-voltage (MV) grid have less impact on voltage profiles than those connected further down the radial network.
- ➢ Voltage Breaches: Voltage breaches under analyzed demand conditions were minimal.
- ➢ Voltage Drop Reduction: D-STATCOM effectively reduces voltage drops and fluctuations.
- ➢ Cost: The cost of a D-STATCOM device is approximately $28,000 (£22,000).
- ➢ Cost-Effectiveness: Despite increasing overall augmentation costs, D-STATCOM offers enhanced controllability and response time, making it a potentially optimal, albeit not the most cost-effective, solution.

Voltage profile at Pillar B - close to Supply transformer	Voltage profile at Pillar E – at centre of network	Voltage profile at Pillar J – farthest from Supply transformer
		

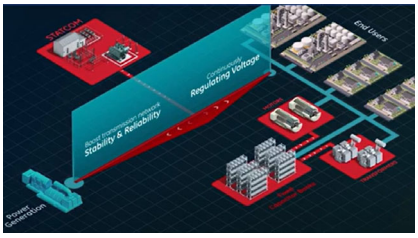
Source: Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level

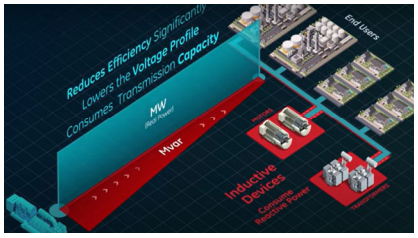
Source: Electric Vehicle Charging Infrastructure and Impacts on Distribution Network," Greening the Grid (GTG)- Renewable Integration and Sustainable Energy (RISE) Initiative, a partnership between USAID and Ministry of Power, GOI, 2020.

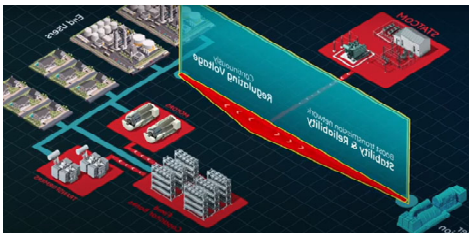
13.2 Mitigating Strategies for Transformer Overloads

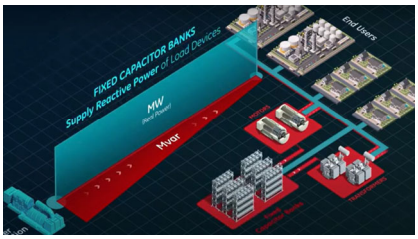
■ STATCOM Mitigation Measures

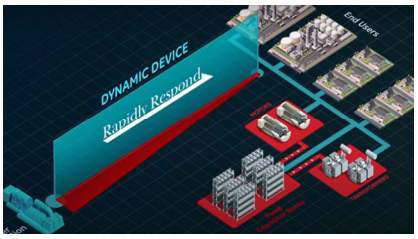
- ➢ Injects three-phase sinusoidal balancing currents to manage voltage deviations.
- ➢ Compensates for reactive power to maintain adequate voltage profiles.
- ➢ Utilizes reactive power based on voltage droop characteristics to control voltage.
- ➢ Adjusts power delivery or absorption according to grid conditions.

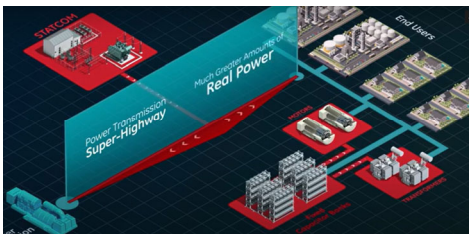












How STATCOM Can Solve Dynamic Grid Problems

Source:How STATCOM Can Solve Dynamic Grid Problems," Grid Solutions, [Video], https://resources.grid.gevernova.com/industry-expert-talks/how-statcom-can-solve-dynamic-grid-problems?v=how_sta_can_sol_dyn_gri_pro, https://www.gegridsolutions.com/youtu, accessed 2024

13.3 Mitigation Strategies for PQ in Distribution Systems

- This summary outlines the Mitigation Measures used to address the power quality issues caused by power electronics in IRVE chargers

- Electric vehicle IRVE chargers convert alternating current (AC) to direct current (DC) to charge batteries, introducing harmonics into the grid due to high-frequency switching converters.
- These harmonics degrade power quality, reduce the lifespan of distribution transformers, and cause issues like overloading, supply-demand imbalances, and voltage fluctuations.
- The current electric vehicle (EV) charging stations encounter various challenges that need to be addressed to ensure reliable and high-quality electricity delivery, as detailed in Table.
- Additionally, Table outlines the positive effects and control features of different FACTS (Flexible AC Transmission Systems) devices on power quality and EV systems.

13.3 Mitigation Strategies for PQ in Distribution Systems

Mitigation Techniques

- Flexible AC transmission systems (FACTS): and voltage-source converters improve power quality and energy efficiency. Distributed FACTS affect power factor and overall grid stability.
- Battery Charger Design: Two-stage chargers using sinusoidal pulse width modulation and predictive duty cycles help control battery current and reduce harmonics.
- Power Factor Correction (PFC): Utilizing interleaved converters and bridgeless CUK converters enhances charging efficiency and reduces total harmonic distortion.
- Grid Stability Tools: Feeder capacitor banks, transformer tap replacements, D-STATCOM, and filters for charging stations help manage power quality issues.
- Modelling EV Loads: Detailed EV load models, combining constant power components and voltage-dependent components, are essential for examining grid impacts.

Advanced Solutions

- Composite Controllers: Designed to manage transformer disturbances, reduce harmonics, and control voltage imbalances.
- Active Harmonic Filters: Parallel-coupled filters provide dynamic reactive power adjustment and reduce harmonics up to the 50th order.
- Optimization Algorithms: Techniques like ant colony optimization, particle swarm optimization, and the Firefly algorithm help mitigate transformer life loss.

13.3 Mitigation Strategies for PQ in Distribution Systems

■ Mitigation Strategies of Voltage profile

➢ **Traditional Methods:**
- Optimal Capacitor Bank Installation: Use optimal capacitor bank installations and tap changers to address voltage deviations.
- Tap Changer Adjustments: Allows for voltage regulation through transformer adjustments.

➢ **Charging Management of EVs:**
- Smart Load Management: Coordinate EV charging with tariff structures and Time-of-Use schemes to improve voltage regulation.

➢ **Decoupled Active and Reactive Power Control:**
- Active Power Control: Adjusts EV charging rates.
- Reactive Power Control: Injects reactive power to stabilize voltage.
- Bidirectional DC fast-charging stations and three-phase off-board chargers with reactive power capabilities help maintain voltage stability.

➢ **LV Distribution Networks:** Voltage drops during peak loads and rises from PV power injection:
- Coordinate EV and PV system operations.
- Employ smart loads with back-to-back converters for voltage regulation.

➢ **MV Networks:** Utilize fast charging stations with decentralized Energy Management Systems (EMS) for effective voltage control without relying heavily on communication systems.

13.3 Mitigation Strategies for PQ in Distribution Systems

■ Mitigation Strategies of Phase Unbalance:

➢ **Voltage Regulators:** Used to reduce voltage unbalance.

➢ **Energy Storage & Compensation:** Devices such as feeder capacitors and DSTATCOMs help improve power qu**ality by addressing voltage unbalance and** variations.

➢ **Charging Management Optimization:** Coordinating EV charging and discharging by adjusting connection points and power rates can balance the system voltage.

➢ **Phase Reconfiguration:** Phase reconfiguration, especially with Time-of-Use tariffs, can effectively reduce unbalance caused by EVs.

■ Mitigation Strategies of Power Losses:

➢ **Coordinated Charging/Discharging:**
- Peak-Load Shaving: Coordinating EV charging and discharging can reduce power losses and manage peak loads.
- Optimal Patterns: Stochastic programming for optimal charging patterns to minimize power losses.
- Load Management: Effective management of EV loads can decrease power losses by up to 10%.
- Real-Time Scheduling Methods: to minimize power losses or voltage drops based on EV availability.

➢ **Renewable Sources:** Aligning EV charging demand with renewable energy sources can also reduce power losses, leveraging the stochastic nature of both

13.3 Mitigation Strategies for PQ in Distribution Systems

- **Mitigation Strategies of Harmonic Sources:**
  - **Conventional Methods:** Power factor correction and shunt active power filters are traditional methods to reduce harmonics.
  - **Alternative Approaches:** harmonic compensators by absorbing or injecting harmonic currents.

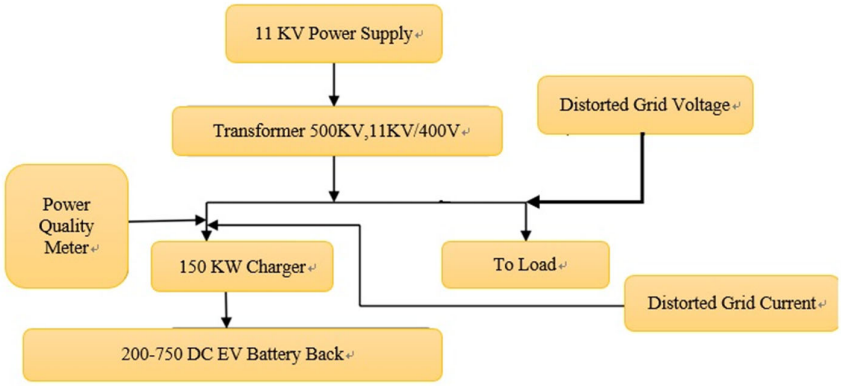
13.3.1 Mitigate Methods for IRVE Impact on the PQ Issues

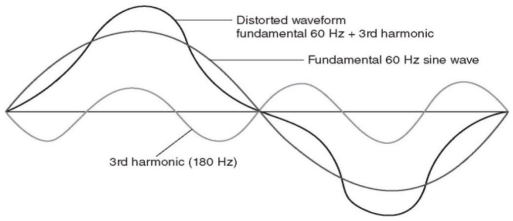
Methods to Mitigate the Impact of IRVE Integration on the PQ

Impacts	Method	Remarks
Voltage profile	Traditional voltage regulators	• Feeder capacitor bank. • Tap changer.
	Charging management of EVs	• Smart load management control • Coordinating EV charging.
	Decoupled active and reactive power control strategy	• The active power control by EV charging, and the reactive power control by injecting reactive power into the grid to regulate the network voltage
Phase Unbalance	Voltage regulators	• Energy storage units. • Feeder capacitor bank. • dSTATCOM
	EV charging/discharging management A phase reconfiguration approach	• Optimal charging/discharging status • Optimal charging/discharging power rates • The time of use tariff.
Power Losses	Coordinating EV charging/discharging	• Optimal coordinated charging/discharging EVs for peak shaving and losses minimization. • Optimal coordinated charging through a stochastic approach. • A real-time scheduling method for EV charging in LV residential distribution system.
	Coordinating with DGs	• Coordinating EV charging demands with DGs and RESs
Harmonic	Traditional filters	• A power factor correction in EV chargers. • A shunt APF for charging stations. However, using shunt APF could increase the current harmonic distortions.
	Absorbing or injecting harmonic currents	• Participating in harmonic and reactive power ancillary service markets
	Coordinating with wind generators	• Consuming harmonic current components from wind generators by EV loads

Source: DOI: 10.1049/iet-est.2018.5023.

13.3.1 Mitigate Methods for IRVE Impact on the PQ Issues





Harmonic distortion where the waveform composed of 3rd and fundamental

Approaches to Mitigate Impact of EV on Power Quality

Impacts	Mitigation techniques	Description
Impact on power losses	Coordinating EV charging/discharging and with distributed generators	Optimal coordinated operation and scheduling of EV charging in low voltage distribution line and to minimize power loss, EV charging demand can be synchronized with distributed and RE sources
Impact on voltage unbalance	Phase reconfiguration technique, voltage regulators, Management of EV charging and discharging	Optimization of EV and phase reconfiguration technique to mitigate voltage unbalance. Flywheels, super capacitors, battery storage systems (BES), capacitive energy storage system (CES) and super conducting magnetic storage system (SMES), DVR, DSTATCOM can be used to reduce voltage unbalance
Impact on voltage fluctuations	Charging management, voltage regulators, active and reactive power control strategy	Transformer tap changes, capacitor bank can be used to reduce voltage fluctuations. Coordinating EV charging used in a control manner to regulate network voltage to reduce voltage fluctuations
Impact on harmonics	Filters, absorb or inject harmonic current	Shunt filter, series filter, resonance filter and hybrid filter, and harmonic analyzer can be used to mitigate harmonics distortion in distribution network. EVs can take part in harmonics and reactive power ancillary services

Source: DOI: 10.1186/s44147-023-00193-w

13.3.1 Mitigate Methods for IRVE Impact on the PQ Issues

Fact Devices and their Impacts on Power Quality and Electric Vehicle Charging System

Filter and fact devices	Features	Drawbacks	Positive impacts and control features in power quality and electric vehicles system
Hybrid LC filters	Efficient, low ripple factor, reliable, high gain, bleeder resistance improves voltage regulation and filtering action	Require tuning of LC circuit, limited standard sizes, L-filter is bulky, Low output DC voltage	Reduction in DC ripple, AC side harmonics, reduced filter VA rating, prevent injection of low order current harmonics into ac mains, reduce electromagnetic interference problem in EV system
Dynamic voltage restorer (DVR)	Small in size, more energy capacity compared to UPS, less cost, higher capacity, less maintenance, voltage balancing capability	Difficult to protect the devices during short circuit due to connected in series, no battery	Very fast response, Precise voltage regulation, Improve and correct short voltage reductions, controlled real and reactive power at load side, compensate power quality issues, i.e., voltage sag and swell when integrated with energy storage devices in EV charging system, absorb harmonic current, controlled charging
Multilevel Inverter	Less no of components, power easily scaled, better electromagnetic compatibility, lower switching loss, boost voltage, reduce voltage stress, THD is low, simple control of active and reactive power	Capacitor and clamp diode is in large number, i.e., system bulky, efficiency poor, high cost, capacitors voltage unbalance	Staircase waveform quality, reduced harmonic distortion, reduce electromagnetic interference problem in EV system, less voltage distortion, operate in bidirectional way in EV system, Increase reliability
Interline power flow controller (IPFC)	Extension of UPFC, combination of series controller and unified controller, control power flow of multiple lines, switches off capacitor bank, current, voltage when excess, control and optimize of transmission line	More no of series converter makes system bulky, less control of capacitor voltage,	Increase stability of grid using Internet of things, improved voltage profile, reduced power loss, enhances dynamic response when combine with superconducting magnetic energy storage (SMES), robustness, reactive power control, damp oscillation
STATCOM without storage	Component smaller than SVC, faster response time, dynamic voltage control, better characteristics, robust and simple, flexible algorithm	More losses, high cost, no harmonic suppression	Controlling voltage, VAR compensation, damp oscillation, dynamic stability, minimize total real power loss, power factor correction
STATCOM with storage	Wide operating range, lower rating than SVC, dynamic voltage control, better characteristics, robust and simple, flexible algorithm, component smaller than SVC, faster response time	More loss, high cost, large DC source required to charge the capacitor, no harmonic suppression	Interface with real power sources, like battery, fuel cell or SMES, controlling voltage, VAR compensation, damp oscillation, automatic gain controller, provide smooth integration of renewable energy, minimize total real power loss and power factor correction in EV system
Static VAR compensator (SVC)	Improve transient, Smoother control, faster response due to no inertia, improve system capability	Slower than STATCOM, Not interface with energy storage sources, expensive, limited overload capability	Control reactive power, overvoltage and dynamic performance of grid, reduce fluctuation on grid voltage, stabilize system, minimize energy loss, improve voltage deviation
Static VAR Generators (SVG)	High reliability, low maintenance, improve transient stability, faster response, static operation	Large DC source required to charge the capacitor, no harmonic suppression	Control damping oscillation, Interface with real power sources, like battery, fuel cell or SMES, controlling voltage, VAR Compensation

Source: DOI: 10.1186/s44147-023-00193-w

13.3.1 Mitigate Methods for IRVE Impact on the PQ Issues

Fact Devices and their Impacts on Power Quality and Electric Vehicle Charging System

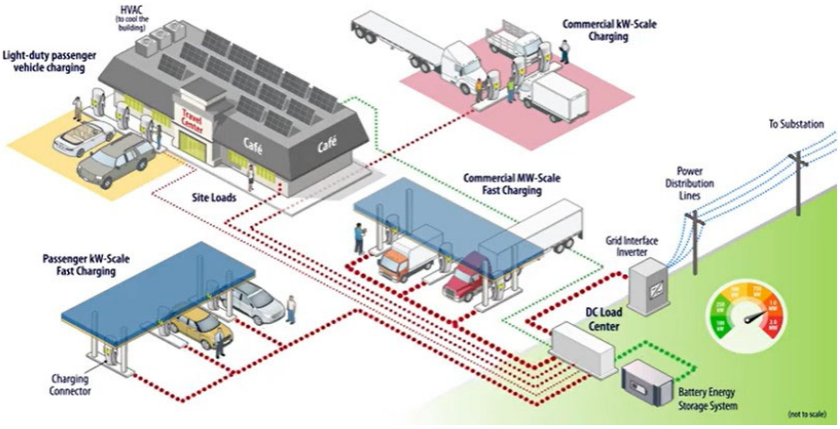
Filter and fact devices	Features	Drawbacks	Positive impacts and control features in power quality and electric vehicles system
Unified power flow controller (UPFC)	Combination of STATCOM and static series compensator, high level of voltage and current achieve, redundancy is possible, bidirectional flow capability, real time control, flexible, capacity expansion possible	System cost high, control complexity when DC linked separated, interruption in voltage not possible, required large number of diodes, inverter and capacitor which makes system bulky, conduction and switching loss high	Control voltage, current, phase and power flow, Control active and reactive power, VAR compensation, damping oscillation, transient and dynamic stability, better voltage regulation than SSSC, minimization of losses, voltage stability, improves dynamic stability of system
Distributed Power flow controller (DPFC)	Provide reactive power compensation, power flow control, System impedance control	Phase shift error increase due to linearization	Transient and dynamic stability improvements, better voltage regulation, improves power transfer capability, Power compensation and low frequency power oscillation, Enhances system load ability
Static synchronous series compensator (SSSC)	Connected in series with transmission line through transformer, eliminate bulky passive component capacitors and inductor, injected voltage managed independently, satisfactory work with high load and low load, increase or decrease transferable power	Expensive, costly, mal operation of relay if degree of compensation and location is not proper	Power factor correction, load balance, reduce harmonic distortion, Series voltage sag compensation, regulate power flow, limit short circuit current, mitigate sub synchronous resonance oscillation in grid
Thyristor controlled Series compensator (TCSC)	Improve system stability, provide nonlinear switching behavior of thyristors, decrease dc offset voltage, improve voltage profile	High level of harmonics due to non-symmetrical harmonics, heating, and additional power losses issue	Control active power flow, suppress oscillation, decrease Dc offset voltages, control power flow, improve the transient stability, limit fault current, mitigate sub synchronous resonance
Thyristor controlled series reactor (TCSR)	Compensate, regulate and damp oscillation power system, decrease dc offset	Heating issue, power loss, switching and conduction loss, costly	Control current, improve transient and dynamic stability,
Series active power filter	Connected in series with grid system, easier to tune, smaller in size, harmonic isolation and harmonic damping, reduce power loss, reliable operation, less dependency on inductors	Large DC power supply require, oscillation, expensive, not handle large amount of power, handle low and moderate frequency	Reactive power compensation, control voltage, mitigate current unbalance, Sag, swell, reduce current harmonics, mitigate harmonic distortion in distribution network, reduce dc ripple, ac side harmonics, and filter VA ratings
Shunt Active power filters	Connected in parallel with grid system, compensate unbalance current and fluctuating current, easy installation, easy to connect parallel line, low implementation cost	Not applicable for high order harmonic, large DC power supply require, large capacitor makes system bulky and expensive, smaller inductor increase ripples	Reactive power compensation, mitigation of current unbalance, reduce harmonic propagation, and inter-harmonic, improve system performance, i.e., reduce current and voltage distortion in distributed grid
Virtual Coordinate System	Combine effect of phase locked frequency multiplier and instantaneous reactive power theory improve charging quality of electric vehicle, reliable operation, response increase	Typical have fast locked problem in PLL multiplier, overshoot and instability, power dissipation in PLL, not accurate under high bandwidth condition, Sensitive to harmonics	Reduced impact of volatile energy, reduced distortion and fluctuation of charging current, improve charging quality of electric vehicle, reduce fluctuation of output voltage, reduce distortion of access current, enhances life of battery and charging components of electric vehicle charger

Source: DOI: 10.1186/s44147-023-00193-w

14. Case Studies: Introduction to Smart Charging and Grid Stability

14.1 Smart Charging & Grid Stability through IRVE

- **Smart Charging:** This approach focuses on managing EV charging to minimize overall load variation, aiming to balance and optimize the energy load.
- **Energinet:** A Danish public enterprise, manages the nation's electricity and gas transmission networks, ensuring reliable energy, supporting market operations, and integrating renewable energy sources. The company also focuses on energy efficiency and EV charging solutions.
- As EV adoption increases, the grid faces greater pressure, emphasizing the need for advanced smart grid integration to prevent destabilization.



Source: Charging Plaza of the Future Concept Uses High Power Charging and Smart Charge Management," NREL.

14.1 Smart Charging & Grid Stability through IRVE

- Denmark aims for 760,000 electric vehicles by 2030, potentially reaching 1 to 1.5 million units at the current sales rate.
- Uncoordinated EV charging could destabilize the grid, causing voltage drops and power losses.
- Without adopting smart and responsible charging as the standard, there is a heightened risk of power outages, necessitating costly and labour-intensive grid expansions at both the distribution (DSO) and transmission (TSO) levels.
- The aim is to actively pursuing systems and solutions within the EV charging sector to support the development of vehicle-to-grid integration and improve grid stability.
- Its recommended collaborating with international TSO counterparts on system design strategies and planning to help shape national policies and ensure effective cross-border alignment.

14.1 Smart Charging & Grid Stability through IRVE

Sustainable Energy Transition meets Mobility Transition

The transition to 100% renewable energy and EV fleets creates significant challenges for the electricity grids



THE KEY TRENDS

1. The number of EVs (including hybrids) expected to grow from 150.000 to 760.000 by 2030. At the current speed, Denmark will possibly even reach 1 -1.5 million EVs.
2. Denmark has expressed an ambition for 100% renewable energy by 2030.
3. The electricity grids cannot facilitate growth with the current charging infrastructure. Extending the grid in time is impossible.

The car batteries can be a stabilizing force in the grid

With EVs gaining market share, EV charging can be a huge threat or part of the solution



HOW WE CAN ADAPT

1. If we redesign the way we charge EVs we can create benefits for all stakeholders.
2. Technologies and business models are available and have been tested in more than 100 projects around the world.
3. A national system design is required to prevent disruptions and to create grid stabilization.

We need to design & realize the system to avoid blackouts

We propose to urgently design a National Responsible Charging System and organize for rapid implementation



POSSIBLE NEXT STEPS

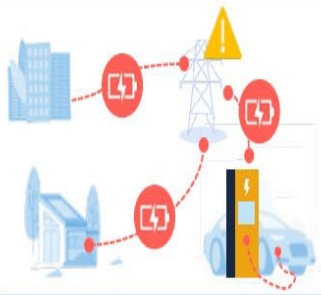
1. Most urgently, we propose a high paced system design project in co-creation with all key stakeholders.
2. Energinet can start the identification of enabling technology solutions and run tests in Denmark.
3. Energinet and partners can initiate a joint implementation program with global leading tech players.

Source: Vehicle Grid Integration Research, Energinet, 2022

14.1 Smart Charging & Grid Stability through IRVE

COSTS OF LOCAL POWER OUTAGES

With current linear charging and the expected growth numbers, most experts expect local and regional disruptions may occur, with significant direct and indirect costs



BLACK-OUT COST ASPECTS

1. **Direct costs:** The direct costs of disrupted power supply include loss of productivity, loss of perishable goods, potential loss of companies leaving to locations with energy supply security.
2. **Indirect costs**: When power supply is not guaranteed, citizens and companies may need to invest in own local safety measures to minimize the potential impact for themselves.

COST OF GRID EXTENSION

Upgrading the electricity grids to facilitate linear charging will require at least 16 Billion DKK in the next 7 years

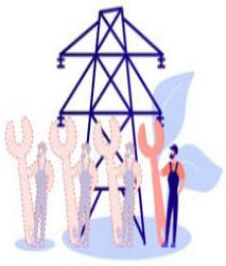


GRID EXTENSION COSTS

1. **Materials:** Grid extension requires expensive and more and more scarce materials.
2. **Machines:** The physical installation requires smart new machinery beyond the current fleets.
3. **Labour:** A majority of total grid extension costs are the labour costs.
   The scarcity of qualified engineers comes on top of this cost aspect (see next column)

LABOR ASPECT OF GRID EXTENSION

Availability of sufficient Technical & Engineering talent may well be the major shortage that would need to solved

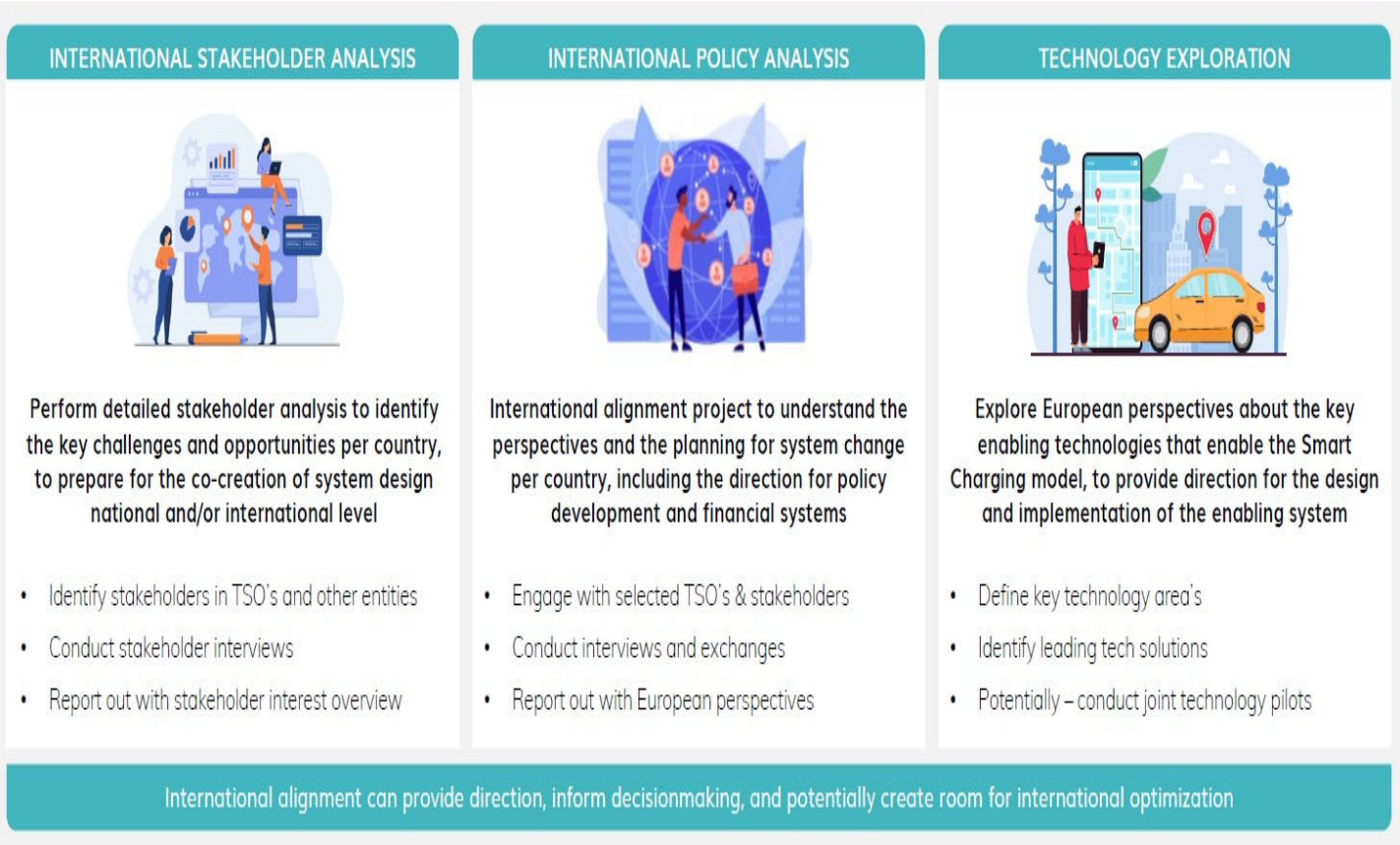


LABOR CHALLENGES

1. **Available qualified people:** Green Power Denmark expects that 29.000 workers yearly until 2030 to upgrade the grids if we do not use the stabilizing capacity of EVs. It will be hard to find enough qualified people.
2. **Costs of qualified people:** Training and paying this workforce is very expensive.
3. **Competing for qualified people with other industries:** We risk to claim scarce technical & engineering talent – competing with other sectors.

Source: Vehicle Grid Integration Research, Energinet, 2022

14.1 Smart Charging & Grid Stability through IRVE



Source: Vehicle Grid Integration Research, Energinet, 2022

14.2 Strategies for Managing EV Growth and Grid Load

■ Victoria‘s ‘Charging the Regions’ project:

➢ By 2030, EVs could account for 80% of new vehicle sales in Australia, leading to a fleet share of 20-25% and a 20 GWh per day increase in grid load.

➢ **To mitigate negative impacts and enhance grid performance, research must focus on:**

➢ **Data Collection:** Understand EV trends and behaviors.

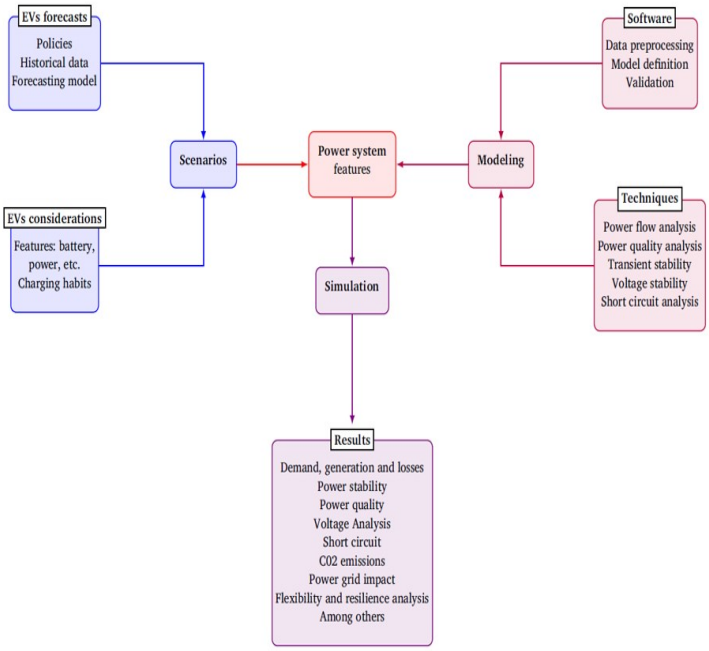
➢ **Business Models:** Develop tariff structures to encourage grid-friendly charging patterns.

➢ **Consumer Behavior**: Explore EV user habits and preferences.

➢ **Mobility & Urban Design:** Assess EV impacts on urban planning.

➢ **Standards & Protocols:** Establish communication between EVs, chargers, and the grid.

➢ **Balancing economic, technical, social, and environmental factors to optimize EVSE location and capacity for maximum utilization and minimal cost.**



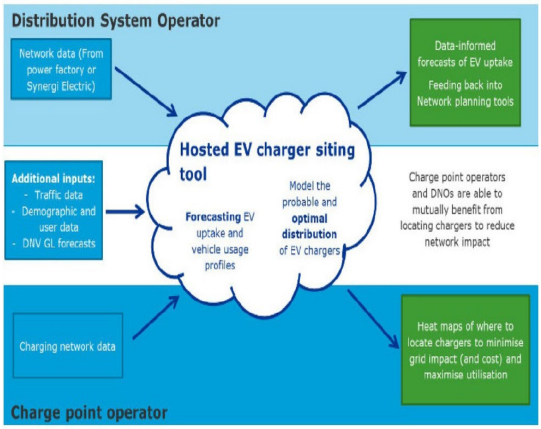
Source: DOI: 10.1016/j.heliyon.2023.e22253

14.2 Strategies for Managing EV Growth and Grid Load

- **Optimization Techniques**:

  - **Multi-criteria Decision-Making**: Balances multiple, often conflicting, criteria to make informed decisions.
  - **Genetic Algorithms**: Uses evolutionary strategies to find optimal solutions through mutation, crossover, and selection processes.
  - **Swarm Optimization**: Mimics natural systems, such as bird flocking, to explore and exploit optimal solutions.
  - **Spatial Analysis & GIS**: Analyzes geographic data to determine optimal locations for EV infrastructure.
  - **Synergi Electric & PowerFactory**:

    - **Network Data Utilization**: Models the impact of EV charging on the grid using detailed network data.
    - **Intelligent Siting and Sizing**: Assists in making informed decisions about where and how much EV charging infrastructure is needed.
    - **Scenario-Based Assessments**: Evaluates potential future demands and infrastructure needs through simulations.





Source: Final Report, RACE for Networks Program, Research Theme N1: Electric Vehicles and the Grid, 2021.

14.3 Infrastructure Enhancements for Future EV Charging

- Typical Modifications Needed in Distribution System Infrastructure to Accommodate Future EV Charging Loads as follows:

  - Upgrade existing distribution transformers to higher capacities.
  - Determine new transformer ratings, tap settings, and locations in the distribution system.
  - Upgrade primary and/or secondary distribution lines to higher capacities.
  - Split existing primary and/or secondary distribution lines into multiple lines.
  - Install new primary and/or secondary distribution lines.
  - Upgrade reactive power compensation devices to higher capacities.
  - Determine ratings and locations for new reactive power compensation devices.
  - Upgrade harmonic filters to higher capacities.
  - Determine ratings, tuned frequencies, and locations for new harmonic filters.
  - Install new distributed generation resources, specifying ratings and integration points within the distribution system.

14.3 Infrastructure Enhancements for Future EV Charging

- Data Considered for Detailed Power System Analysis:
  - Single Line Diagram (SLD) for HV feeder distribution.
  - Peak load demand records for HV feeders over the past 5 years.
  - Distribution transformer ratings, voltage ratios, vector groups, and impedance.
  - Cable and conductor characteristics.
  - Current-carrying capacities of HV feeders.
  - Details of EV charging stations.
  - GIS coordinates for EV charging loads on HV feeders.
  - Existing and future rooftop solar PV system penetration over the next 5 years.

14.4 Guidelines of IRVE Connection on Power Systems

General Framework of Connection Guidelines for Integrating IRVE into Power Distribution Systems

Category	Description
Electrical Requirements	Specifies voltage levels, current capacity, and grounding standards for connecting IRVE to the grid. Ensures safe electrical integration to avoid overloads, short circuits, or instability in the distribution network.
Communication Protocols	Defines the communication standards between EV chargers and the grid, such as the Open Charge Point Protocol (OCPP). Ensures compatibility for data exchange, remote monitoring, and control of charging stations.
Safety Standards	Outlines safety measures for both the infrastructure and users, including insulation, fault protection, and emergency shutoff mechanisms. These standards ensure safe operation under various conditions.
Interoperability	Guidelines that ensure different charging systems, regardless of manufacturer, can work together within the grid. This includes standardizing connectors, software, and data formats for seamless operation.
Regulatory Compliance	Ensures adherence to national and international regulations, such as those related to emissions, energy efficiency, and power quality. This compliance ensures the system meets legal requirements for operation.
Grid Impact Assessment	Guidelines for assessing the potential impact of IRVE on the grid, including load management, demand response, and the integration of renewable energy sources. Ensures that the grid can handle additional loads efficiently.
Installation Procedures	Step-by-step procedures for the physical installation of IRVE, including site selection, permitting, and grid connection processes. Ensures consistency and safety during deployment.
Monitoring / Control	Protocols for real-time monitoring and control of IRVE, allowing for the optimization of charging schedules, fault detection, and load balancing. This ensures reliable operation and enhances grid stability.
Cybersecurity	Defines the measures to protect IRVE systems from cyber threats, ensuring the security of data and grid operations. These guidelines protect against unauthorized access and cyberattacks.
Maintenance / Operations	Standards for ongoing maintenance and operation of IRVE systems, ensuring long-term reliability, safety, and efficiency. Includes regular inspections and performance assessments.

Source: JICA Expert Team

Presentation Material 2- 13

Activity 2-4-2 & 2-4-3 Identify and Discussion on the Items to be Included in the Guideline

Identify and Discussion on the Items to be Included in the Guideline

Activity 2-4-3

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

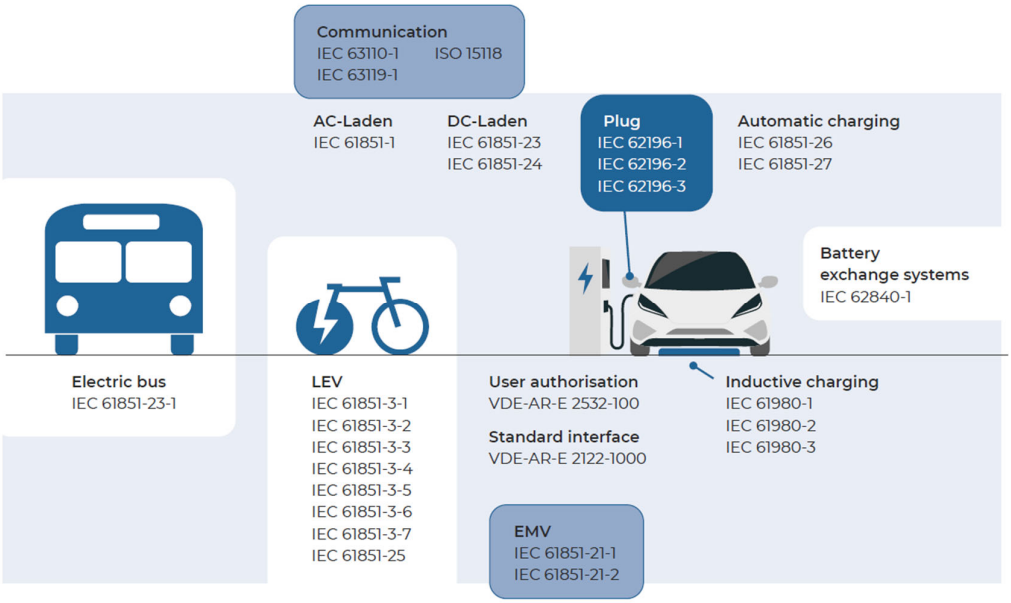
1. Technical Standards for EV Chargers
2. Grid Integration and Power Quality
3. Safety and Performance Benchmarks
4. Installation and Operational Guidelines
5. Impact on Distribution Networks
6. Charging Infrastructure Planning and Deployment
7. Standards for EV Charging Modes and Levels
8. Renewable Energy Integration
9. Cybersecurity and Network Protection
10. Monitoring and Maintenance

1. Technical Standards for EV Chargers

1. Technical Standards for EV Chargers

- **Standards**:
- **IEC 61851**: Conductive Charging Systems
  - General requirements for conductive charging, charging modes (1 to 4), communication protocol, and safety requirements.
- **ISO 15118**: Vehicle-to-Grid (V2G) Communication
  - Protocol for smart charging and bi-directional energy flow, including automated authentication and payment via Plug & Charge.
- **SAE J1772**: EV Charging Connectors
  - Standard for EV connectors used in North America and Asia for Level 1, 2, and DC fast charging.
- **IEC 62196**: EV Plugs, Socket-Outlets, and Couplers
  - Physical and electrical characteristics of plugs and connectors for global interoperability.

1. Technical Standards for EV Chargers



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

1. Technical Standards for EV Chargers

IEC Standards Relating to IRVE Quick Chargers

EV conductive charging system	
IEC 61851-1	General requirements
IEC 61851-21-1	EV on-board charger EMC requirements for a conductive connection to an AC/DC supply
IEC 61851-21-2	Electric vehicle requirements for conductive connection to an AC/DC supply – EMC requirements for off board electric vehicle charging systems
IEC 61851-23	DC electric vehicle charging station
IEC 61851-24	Digital communication between a D.C EV charging station and an electric vehicle for control of D.C charging
IEC 61851-25	DC EV supply equipment where protection relies on electrical separation
Plugs, socket-outlets, vehicle connectors, and vehicle inlets conductive charging of EVs	
IEC 62196-1	General requirements
IEC 62196-2	Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories

1. Technical Standards for EV Chargers

IEC Standards Relating to IRVE Quick Chargers

IEC 62196-3	Dimensional compatibility and interchangeability requirements for DC and AC/DC pins and contact-tube vehicle couplers
Electromagnetic compatibility (EMC)	
IEC 61000-3-2	Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
IEC 61000-3-12	Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase
IEC 61000-13-15	Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase
Degrees of protection provided by enclosures	
IEC 60529	Degrees of protection provided by enclosures (IP Code)
IEC 62262	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)

1. Technical Standards for EV Chargers

IEC Standards Relating to IRVE Quick Chargers

Environmental testing	
IEC 60068-2-75	Environmental testing - Part 2-75: Tests - Test Eh: Hammer tests
Plugs, socket-outlets and couplers for industrial purposes	
IEC 60309-1	General requirements
Quality management systems	
ISO/IEC 9001:2015	Requirements
Conformity assessment	
ISO/IEC 17021-3	Requirements for bodies providing audit and certification of management systems, Competence requirements for auditing and certification of quality management systems
ISO/IEC 17025	General requirements for the competence of testing laboratories
ISO/IEC 17067	Fundamentals of product certification and guidelines for product certification schemes

Source: JICA Research Team

2. Grid Integration and Power Quality

2. Grid Integration and Power Quality

- **Standards**:
- **IEEE 2030.5**: Smart Grid Interoperability
  - Guidelines for communication between EV charging infrastructure and the grid.
- **IEEE 519-2014**: Harmonics Control
  - Limits for harmonic distortion and voltage stability to prevent grid instability.
- **IEC 61000-3-2/3**: Electromagnetic Compatibility (EMC)
  - Sets limits for harmonic emissions to avoid interference with other electrical systems.
- **IEC 61850**: Substation Communication
  - Communication protocol for integrating EV chargers with distribution network systems.

2. Grid Integration and Power Quality

- **Japan Electric Association Guidelines**
  - **Harmonics and Distortion Guidelines:** 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
- Various international standards, such as IEC 61000-3-2, IEC 61000-3-12, and IEEE 519-2014, establish limits for these emissions to ensure compatibility and prevent interference within electrical systems.

2. Grid Integration and Power Quality

- The following are key guidelines for harmonic current emission standards, detailing limits and controls to ensure compatibility and grid stability.
  - IEC 61000-3-2: Establishes limits for harmonic current emissions from equipment with input current ≤ 16 A per phase.
  - IEC 61000-3-12: Specifies limits for harmonic currents from equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase.
  - IEEE 519-2014: Provides guidelines for controlling harmonics and ensuring voltage stability to prevent fast chargers from impacting the power grid.
  - IEC 61000-3-2/3: Focuses on electromagnetic compatibility (EMC) by setting limits on harmonic emissions to avoid interference with other electrical systems.

2. Grid Integration and Power Quality

Guidelines for Harmonics

Guideline	Japan Electric Association Guidelines 9702-2013 Technical Guidelines for Harmonic Suppression
Objective	The guidelines have been developed with the intent to suppress the harmonic outflow current from customers who receive power at high voltage or extra high voltage so that a wide range of equipment connected to power systems can be protected from harmonics and security failures owing to equipment damage can be prevented.
Definition	• High-voltage system: Over 600 V to 7000 V or lower • Extra high-voltage system: Over 7000 V • Harmonic wave: A sinusoidal wave with a frequency that is an integer multiple of more than twice the fundamental frequency, targeting up to the 40th order

2. Grid Integration and Power Quality

Guidelines for Harmonics

Procedures	There are two steps for determining the necessity of countermeasures for harmonics: "determination based on equivalent capacity" and "determination by harmonic outflow current." 1) Determination based on equivalent capacity: The sum of the rated equipment capacity multiplied by a conversion factor is obtained for all equipment, and whether the value obtained exceeds the limit for each voltage class will be determined. The conversion factor is set by dividing into about 30 types according to the circuit used in the equipment. 2) Determination by harmonic outflow current: When it is determined that countermeasures are required by the "determination based on equivalent capacity," a more detailed study is conducted in the "determination by harmonic outflow current" step. Specifically, harmonic current is obtained by the harmonic current (manufacturer's rated value) generated by each item of equipment * maximum equipment availability factor * correction factor (reduction rate) by customer scale; from this, the general harmonic current value assumed to be from the system is subtracted, and the value obtained is compared with the upper limit of harmonic outflow current per 1 kW described

2. Grid Integration and Power Quality

Guidelines for Harmonics

	in the Guidelines. With this, the final determination on the necessity for countermeasures will be made.
Exceptions	Equipment subject to the application of "Limits for generated harmonic current (equipment input current ≦ 20 A per phase)" in JIS C 61000 -3 -2 should be outside the scope of the Technical Guidelines for Harmonic Suppression because each item of equipment has its own harmonic suppression countermeasures.

Source: Necessary Regulations, Standards for Quick Chargers, Effect on Grid Stability, Business Model, Promotional Policies, TEPCO, 2019

2. Grid Integration and Power Quality

Upper Limit Values for Harmonic Outflow Current per KW of Equivalent Value of Contract Capacity

Receiving Voltage	Fund							
	5th	7th	11th	13th	17th	19th	23rd	Over 23rd
6.6 kV	3.5	2.5	1.6	1.3	1.0	0.90	0.76	0.70
22 kV	1.8	1.3	0.82	0.69	0.53	0.47	0.39	0.36
33 kV	1.2	0.86	0.55	0.46	0.35	0.32	0.26	0.24
66 kV	0.59	0.42	0.27	0.23	0.17	0.16	0.13	0.12
77 kV	0.50	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
220 kV	0.17	0.12	0.08	0.06	0.05	0.04	0.03	0.03
275 kV	0.14	0.10	0.06	0.05	0.04	0.03	0.03	0.02

Source: Japan Electric Association Guidelines 9702-2013

2. Grid Integration and Power Quality

Guidelines for Flicker

Guideline	Determined by each electric utility independently
Standard and determination	In Japan, $\Delta V10$ is set as the standard, which is the sum of the squares of "voltage fluctuation per frequency band multiplied by luminous coefficient." In general, if $\Delta V10$ exceeds 0.45, countermeasures are required. Note that in many cases, it is difficult to calculate $\Delta V10$ directly, and some electric utilities decide the necessity of countermeasures based on momentary voltage fluctuations. To be more specific, voltage fluctuation ΔV is obtained based on the current waveform (striking current waveform, and so on) indicated by the equipment manufacturer and the impedance of the connected power system. After verifying whether the value obtained is equal to or less than the voltage fluctuation specified by the electric utility, the necessity of countermeasures will be determined.

Source: Kanto Denki Hoankyokai

2. Grid Integration and Power Quality

Table: Guidelines for Instantaneous Voltage Drops

Guideline	Determined by each electric utility independently
Procedure	The determination is made by each power company independently, but it has also been considered simultaneously with voltage flicker by some electric utilities. On the other hand, when power generation facilities are interconnected, installers need to follow the guidelines issued by the regulator in 2004: "Guidelines for Technical Requirements of Interconnections Securing Power Quality". For interconnection to low and high voltage lines, voltage drops shall be within 10% of the normal voltage when paralleling/paralleling off the generators and the duration which requires countermeasures against instantaneous voltage drop shall be up to approximately 2 seconds. For interconnection to extra high voltage lines, the range of voltage from the normal voltage shall be 2%.
Equipment affected	Equipment types affected by instantaneous voltage drops were mainly magnet switches and mechanical type control devices for large scale motors in the 1970's. The range has been expanded since then. The following figure shows the types of equipment which are affected by instantaneous voltage drops.

Source: Kanto Denki Hoankyokai

3. Safety and Performance Benchmarks

3. Safety and Performance Benchmarks

- **Standards**:
- **UL 2594**: EV Supply Equipment Safety
  - Safety standard ensuring EV charging equipment meets fire, electrical shock, and mechanical safety requirements.
- **ISO 17409**: Safety Specifications for EV Charging
  - Safety protocols for electrical circuits, emergency shutdown, and overload protection.
- **EN 61851-23**: DC Fast Charging Stations
  - Safety standard for DC fast chargers, including power output, voltage regulation, and thermal management.

4. Installation and Operational Guidelines

4. Installation and Operational Guidelines

- **Standards**:
- **IEC 60364**: Electrical Installations of Buildings
  - Guidelines for wiring, grounding, conduit installations, and overcurrent protection.
- **IEC 60947**: Low-Voltage Switchgear and Controlgear
  - Covers electrical protection and control devices for the installation.

5. Impact on Distribution Networks

5. Impact on Distribution Networks

- **Standards**:
- **IEC 61850**: Communication Networks and Systems in Substations
  - Protocol for integrating EV chargers and grid communication for load balancing and grid control.
- **IEEE 1547**: Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems
  - Outlines guidelines for integrating distributed energy resources (like EV chargers) into the grid without affecting the grid's integrity.

6. Charging Infrastructure Planning and Deployment

6. Charging Infrastructure Planning and Deployment

- **Standards**:
- **IEC 61980**: Electric Vehicle Charging Systems (EVCS) - General Requirements
  - Guidelines for planning the layout of charging stations and integration with the grid, including load forecasting and energy usage patterns.
- **IEEE 1668**: Standard for Design of Electric Vehicle (EV) Charging Systems
  - Provides guidance on planning and designing EV charging infrastructure for public and private spaces.

7. Standards for EV Charging Modes and Levels

7. Standards for EV Charging Modes and Levels

- **Standards**:
- **IEC 61851**: Conductive Charging Systems (covers Modes 1 to 4)
  - Defines the modes of EV charging:
    - **Mode 1**: Slow AC charging via a standard household socket.
    - **Mode 2**: Faster AC charging with basic communication between vehicle and charger.
    - **Mode 3**: Dedicated EV charging infrastructure with enhanced safety and fast AC charging.
    - **Mode 4**: DC fast charging for high-power public fast-charging stations.

8. Renewable Energy Integration

8. Renewable Energy Integration

- **Standards**:
- **ISO 50001**: Energy Management Systems
  - Guidelines for integrating renewable energy sources (solar, wind) into EV charging infrastructure for sustainability.
- **IEEE 1547**: Distributed Energy Resources Interconnection
  - Outlines standards for connecting renewable energy systems to the grid and ensuring safe and reliable operation when integrating with EV chargers.

9. Cybersecurity and Network Protection

9. Cybersecurity and Network Protection

- **Standards**:
- **IEC 62443**: Industrial Communication Networks – Network and System Security
  - Addresses cybersecurity for industrial automation and control systems, including EV chargers.
  - **ISO 15118 Protocol: Enhancing Security and Interoperability in IRVE Integration**

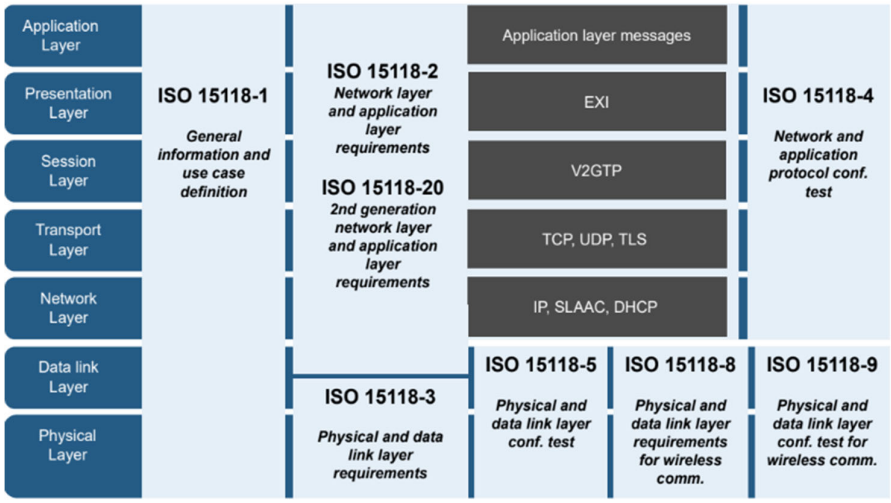
ISO 15118-1	Presents the overall flow of communication and general use cases
ISO 15118-2	Deals with the requirements of messages exchanged by EV and EVSE over the top 5 layers of the Open System Interconnection (OSI) model.
ISO 15118-3	Deals with the functionalities of the bottom 2 layers of the OSI model which are physical and data link layer requirements.
ISO 15118-4	Includes the conformance tests for ISO 15118-2 only which deals with layers 3 and up and does not consider the power flow between EV and EVSE.

- **ISO/IEC 27001**: Information Security Management Systems
  - Information security standards applicable to data protection and cybersecurity for networked EV chargers.

9. Cybersecurity and Network Protection

- **ISO 15118 Protocol: Enhancing Security and Interoperability in IRVE Integration**
  - **ISO 15118** is a critical **front-end protocol** that connects **Electric Vehicles (EVs)** with the **charging infrastructure**, playing a pivotal role in ensuring smooth communication between the vehicle, the charging station (IRVE), and the central management system (CMS).

ISO 15118 Protocol Stack and How the Different Parts of the Standard Map.



Source: Smart and secure EV Charging with NXP secure solutions, AN13645, 2022

10. Monitoring and Maintenance

10. Monitoring and Maintenance

- **Standards**:
- **IEC 61557**: Electrical Safety in Low-Voltage Distribution Systems
  - Guidelines for monitoring the electrical performance of installations, including monitoring and maintenance of EV chargers.
- **IEC 60364-7-722**: Special Installations or Locations – Charging Stations
  - Guidelines for maintaining EV charging infrastructure and ensuring safety.

Presentation Material 2- 14

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

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

Activity 2-4-1

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-

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   1.2 Global Strategies for IRVE Expansion
   1.3 Dedicated Connections for Individual Residents
   1.4 IRVE Connectivity Challenges for MUD
      1.4.1 Overcoming Connectivity Challenges for MUD
      1.4.2 Supporting IRVE Charging in MUD
      1.4.3 Metering and Billing Solutions for Charging in MUD
      1.4.4 Make-Ready Programs: Enhancing IRVE in MUD
      1.4.5 Parking Connectivity Strategies for IRVE in MUD
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   1.7 Streamlining Connectivity and Payment Systems
2. Utility Engagement in Power Input Planning for DCFC-IRVE
   2.1 Connections Deployment of DCFC-IRVE
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   3.2 Overview of Standardization in IRVE
   3.3 Architecture of a Smart Charging System
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   3.5 ISO 15118 Protocol
      2.5.1 PKI and Digital Certificates
4. Cybersecurity in IRVE: Securing the Infrastructure
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   4.7 Cybersecurity Risks in IRVE Data Flow
   4.8 Enhancing Cybersecurity for IRVE and Power Grid

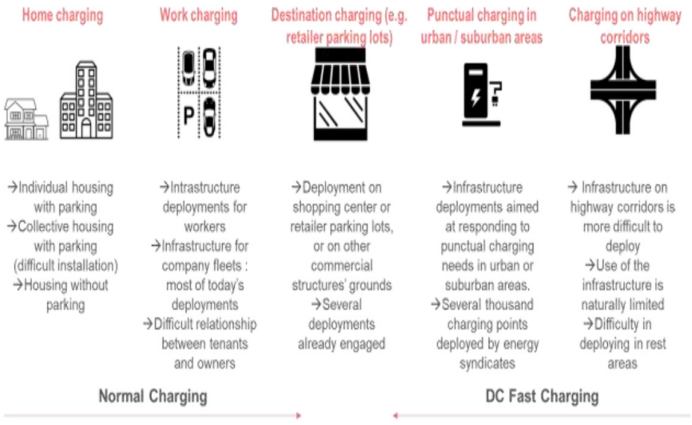
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5. Introduction of Japan's Experience on DSM
- 5.1 Necessity of Promoting DSM
- 5.2 New Role Expected of DSM
- 5.3 Trend in (DSM): Advanced (DR) through (VPP).
- 5.4 Integrating V2G with DSM for Grid Stability

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.

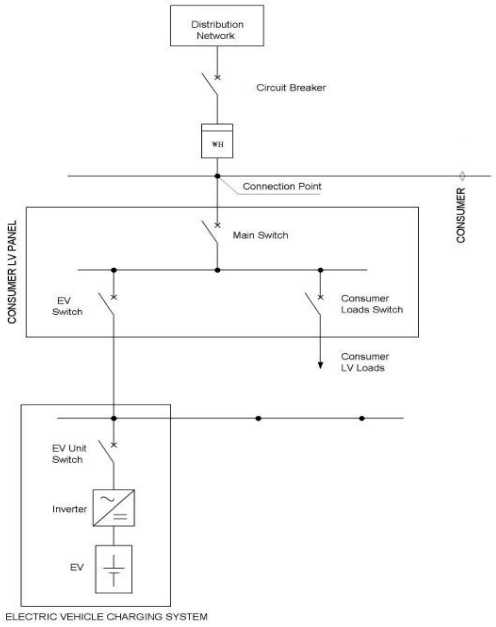
1.2 Global Strategies for IRVE Expansion

■ 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

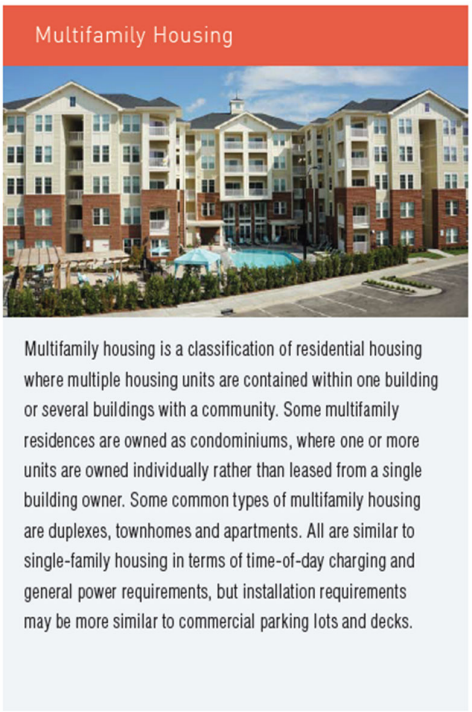
Source:This is a General Scheme

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

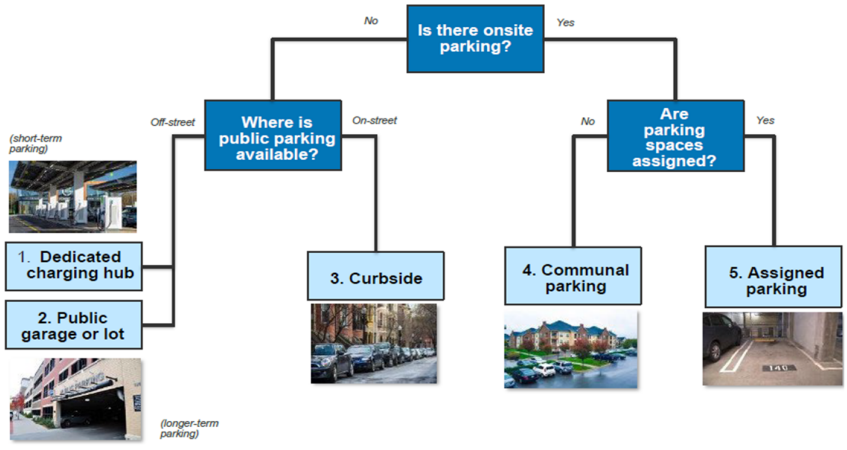
- **Installation Challenges:** In collective housing with dedicated parking, installing IRVE charging points can be difficult due to insufficient infrastructure. While residents can request installations, the process is often costly and time-consuming.
- **Cost of Electrical Upgrades:** As more residents 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

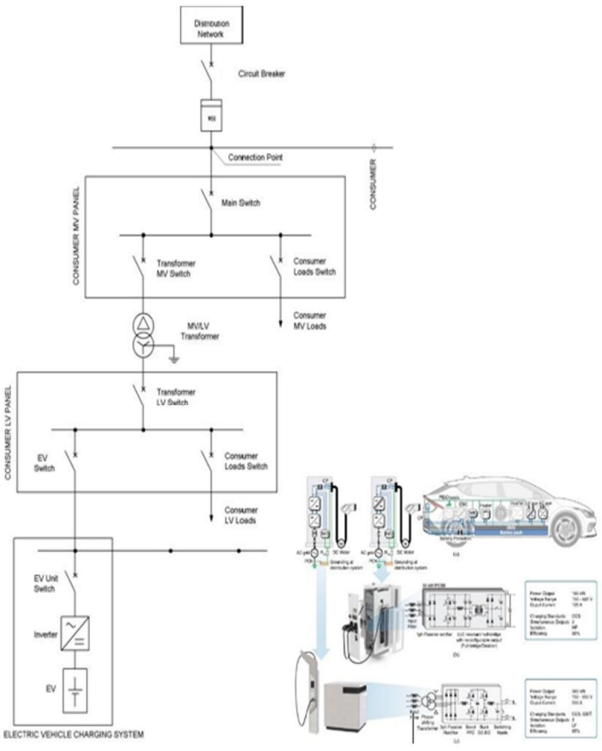
- **Impact of Parking Arrangements on IRVE Solutions**
  - The type and location of parking arrangements significantly affect EV charging integration in MUDs.
  - Options include curbside charging, off-street shared chargers, and assigned parking spots, each requiring different strategies.
- **Charging 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**.

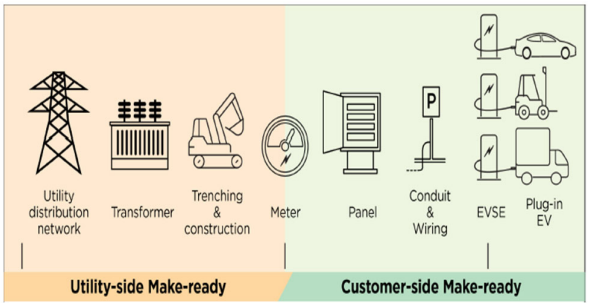
1.4.3 Metering and Billing Solutions for Charging in MUD

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.

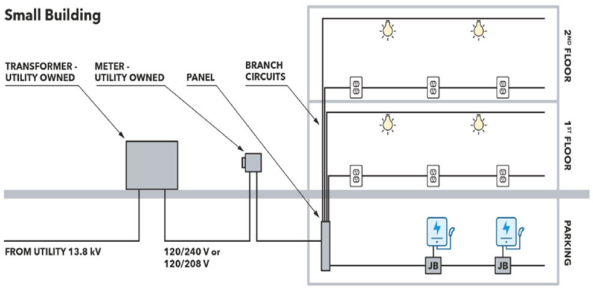


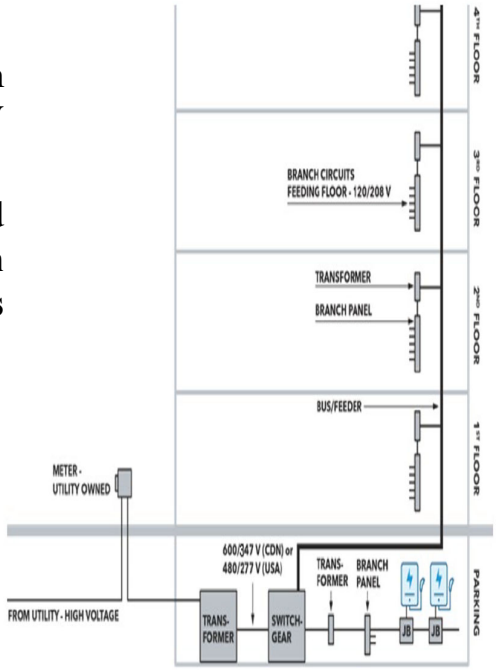
Utility-side and customer-side make ready infrastructure.
Source: NRDC. 2021

  - **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.

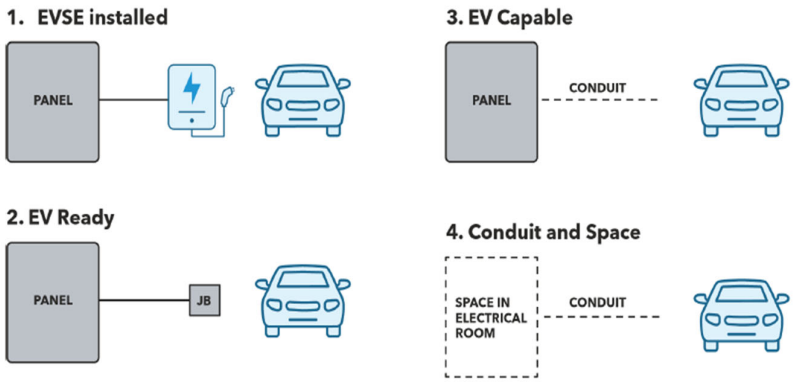




Electrical systems in a smaller building.
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

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.

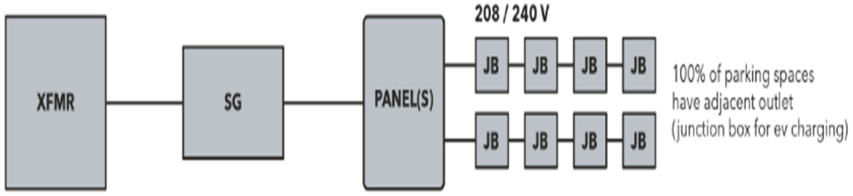
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

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.

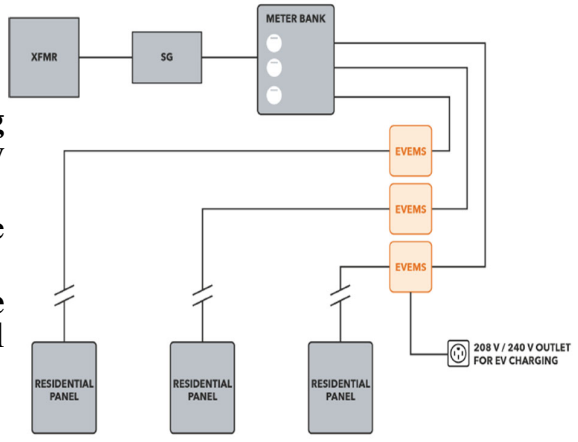
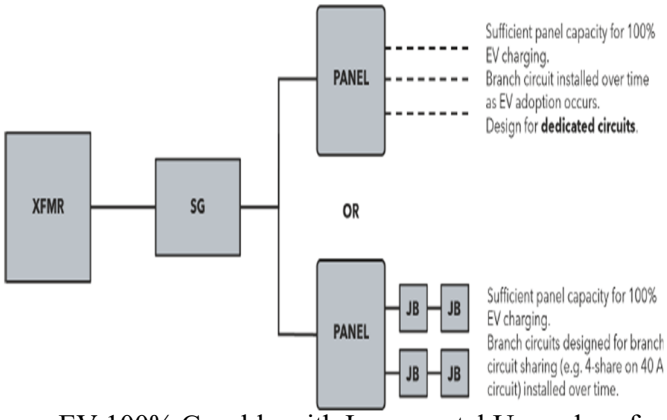


Figure: EV Ready with Level 2 outlets designed for feeder monitoring of residential unit's electrical panels.

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**.

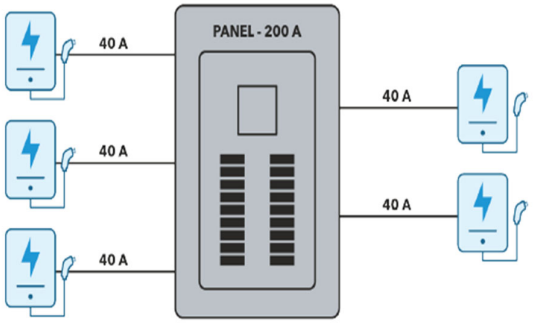


EV 100% Capable with Incremental Upgrades of Branch Circuits.

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.

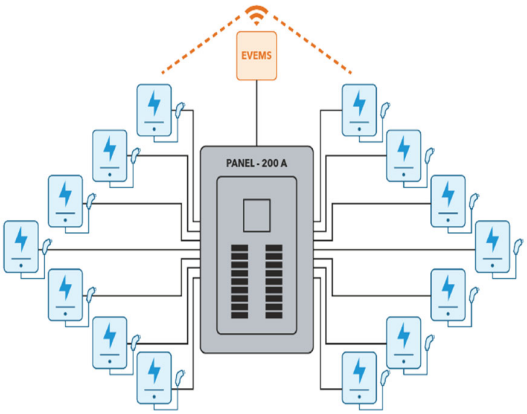
Source: Futureproofing Multifamily Buildings for EV Charging, Dunsky Energy + Climate Advisors, 2023

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

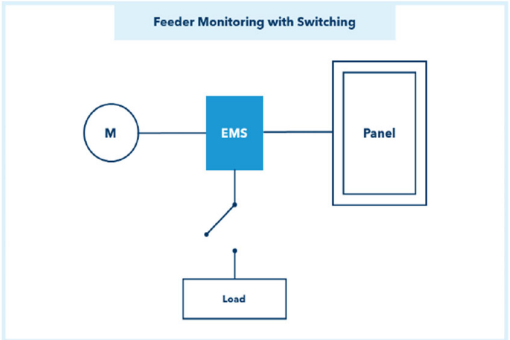
➢ Feeder Monitoring

- 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.

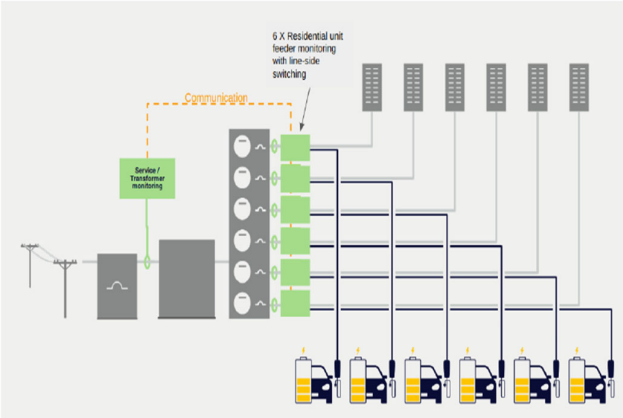


Feeder Monitoring with Switching.

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

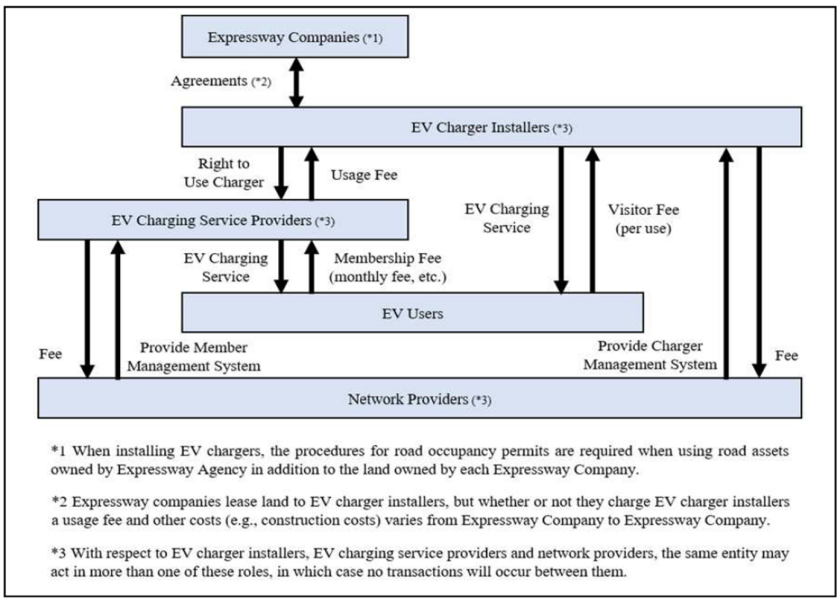
- **Expressway Companies and Expressway Agency**
  - **Role**: Responsible for constructing, operating, and maintaining Service Areas (SA) and Parking Areas (PA) along expressways.
  - The **Expressway Agency** owns the road assets and is an independent body.
  - **Land Use Permission**: Installing EV 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

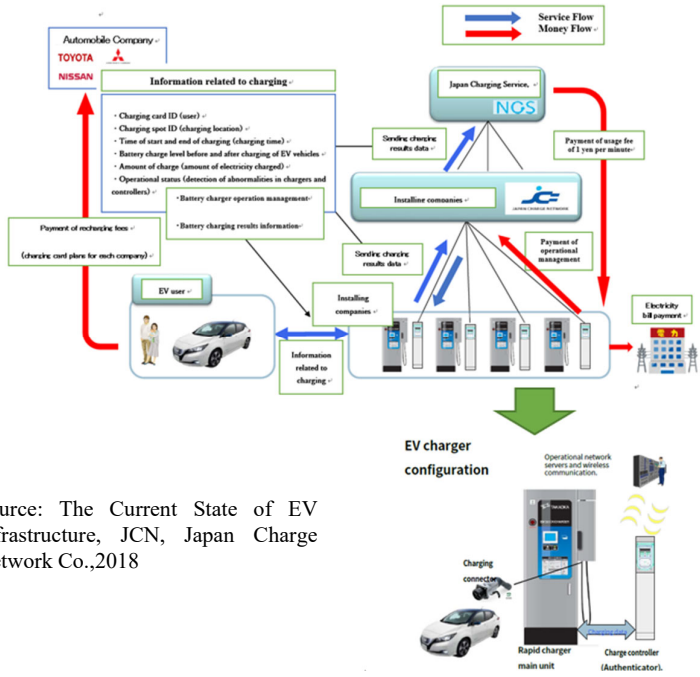
- NCS manages the nationwide network, ensuring a user-friendly experience for EV drivers.
- Allows charger installers to join and provides a unified platform for accessing all chargers within the network.

■ 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.



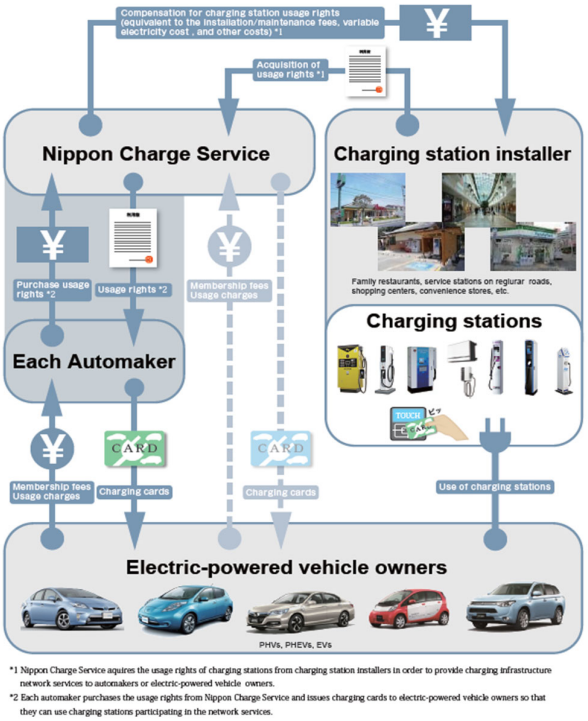
Source: The Current State of EV Infrastructure, JCN, Japan Charge Network Co.,2018

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.

2. Utility Engagement in Power Input Planning for DCFC-IRVE

2.1 Connections Deployment of DCFC-IRVE

- DISCOMs play a key role in supporting EVs and IRVE sites. Site hosts and developers should engage with DISCOMs early to ensure the site's electric service can accommodate chargers or plan necessary upgrades. Providing detailed information, such as site plans and expected electrical load, helps DISCOMs assess capacity and determine if grid enhancements are required. Early engagement is crucial to establish realistic timelines, as interconnection and service upgrades can take longer than anticipated.
- For DCFC chargers, DISCOMs may need to upgrade the grid to meet high-power demands, including enhancing transformer capacity and increasing wire amperage. These upgrades involve significant infrastructure changes, including labour, contracting, and design work. Early coordination with DISCOMs ensures smooth deployment and avoids delays.
- The first step in developing EV charging infrastructure is assessing the energy needs of each charger based on daily usage (load profile) and the required charging window. The necessary information and calculations for this process are outlined in the accompanying figures and examples.

2.1 Connections Deployment of DCFC-IRVE

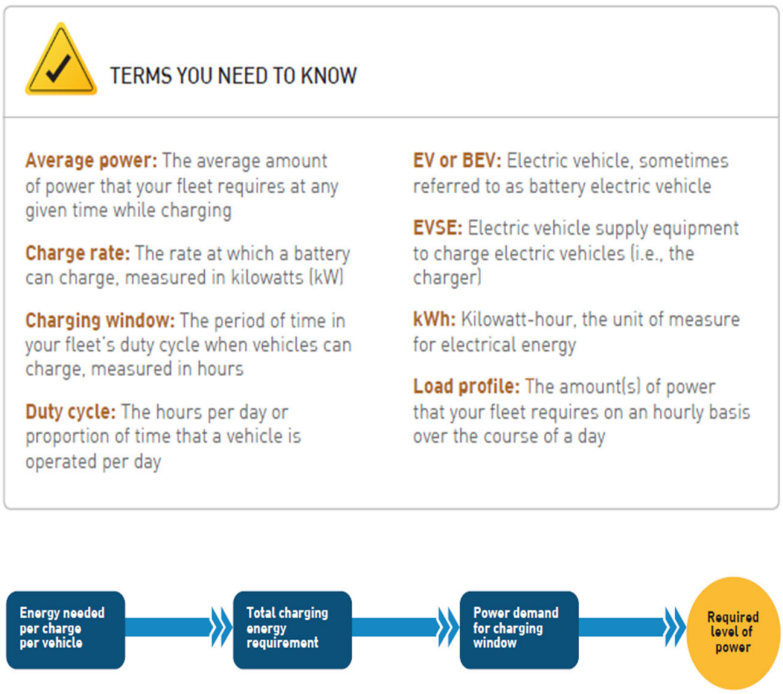


Figure: Components and process for planning the load profile.

Source: A Guidebook to Fleet Electrification and Infrastructure, PG&E, 2019.

2.2 Power Input Dimensioning and Planning

- For the safe and reliable operation of Electric Vehicle (EV) charging stations, it is crucial to ensure the correct dimensioning of the power input. The planning process should consider the following factors:

- **Load Studies and Grid Capacity**: Conduct load studies to predict the demand for power based on the number of charging points and expected usage patterns. This will enable better integration with the grid and more accurate power planning.
- **Grid Infrastructure Expansion**: Ensure that the existing grid infrastructure can handle the high-power demand from charging stations. For larger stations with multiple charging points, this may require the installation of additional transformers or substations. Flexibility in planning is necessary to ensure the infrastructure can be adapted to meet future demand.

2.2 Power Input Dimensioning and Planning

- This checklist consolidates the IEC standards that are crucial for the safe, efficient, and future-ready installation and operation of DC fast charging stations. By adhering to these IEC guidelines, including **IEC 61851-23**, **IEC 62893**, **IEC 60364-7-722**, and **IEC 61851-25**, **DISCOMs** can ensure:
  - **Compliance** with international standards for electrical safety, power quality, and infrastructure resilience.
  - **Reliability** in providing scalable and safe charging infrastructure for electric vehicles.
- This comprehensive approach will help ensure that DISCOMs are fully compliant with necessary IEC standards, enabling the development of a robust, sustainable, and future-proof EV charging network.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- EV-FC Charging Modes 4: This system, provides DC charge via a tethered cable, it offers faster charging and is found at service stations and public parking.
- Charging Capacity and Infrastructure Requirements:
  - **Three-Phase AC and DC Charging**: For higher charging capacities, **three-phase AC** or **DC fast charging** systems are required. DC charging systems capable of handling **up to 500 A charging currents** allow for rapid charging with **capacities exceeding 300 kW**, especially for vehicles operating at **800 V**.
  - **Increasing Charging Points and Infrastructure Expansion**: As the number of charging points increases, the required **AC power inputs** can escalate to **several MW**, necessitating **grid infrastructure expansion** to support the load.
  - **Voltage Quality (IEC 61000-4-30)**: Ensure that the **voltage** supplied to the charging station is stable and within acceptable limits to avoid damaging sensitive equipment. This can be managed by using **voltage regulation devices** when necessary.
  - **Power Factor Correction (IEC 61000-3-2)**: Implement **power factor correction devices** to maintain a stable **power factor** and prevent inefficient power consumption, which could disturb the grid's stability.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **Cable Selection (IEC 62893-4-1 / IEC 62893-4-2)**

➢ **Cable Type**: Ensure cables comply with **IEC 62893-4-1** (for DC charging without thermal management) or **IEC 62893-4-2** (for DC charging with thermal management).

➢ **Cable Specifications**:

- **Rated Voltage**: Ensure cables are rated for **1.5 kV DC** for high-power DC charging.
- **Conductor Size**: Choose cable sizes ranging from **4–150 mm²** for power cores to meet voltage drop and current requirements. Larger sizes may be required for future expansion.
- **Thermal Management**: For higher power capacities (greater than **200 A**), ensure appropriate thermal management systems to avoid overheating.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **4. DC Charging Standards (IEC 61851-23)**

➢ **Charging Systems (CCS)**:

- Ensure the charging system supports **Combined Charging System (CCS)**, capable of delivering **up to 500 A charging currents** and **300 kW charging capacities** for vehicles capable of **800 V** fast charging.

➢ **Infrastructure Requirements**:

- Ensure charging stations are designed to handle **high current loads (several MW)** for multiple charging points, and assess the need for **grid upgrades** to accommodate this load, ensuring compliance with **IEC 61851-23** and **grid connection requirements**.

➢ **Electrical Separation, Protection, and Safety**:

- **Separate Radial Circuits**: Install each final circuit as a **separate radial circuit** from the fixed electrical installation, following IEC 60364-7.
- **Cable Protection**: Ensure cables are **metal-sheathed** or installed in appropriate conduits to protect against physical damage and surges, in compliance with IEC 60364-7-722 and IEC 61851-1.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **Circuit Protection**: Install **high-breaking capacity (HBC) fuses** or **miniature circuit breakers (MCBs)** to prevent electrical hazards, ensuring compliance with IEC 60947-2.
- **Residual Current Device (RCD)**: Install **Type A RCDs** with a residual operating current not exceeding **30 mA, in line with IEC 60364-7**.
- **Switching Devices**: Install **ON/OFF switches** upstream of charging sockets to allow for proper switching after connection/disconnection, following IEC 61851-1 guidelines.

➢ **Electrical Isolation**: Ensure compliance with **IEC 61851-25** for electrical separation between the EV and charging infrastructure, preventing unwanted current flow in case of faults.

➢ **Overcurrent Protection Devices (OCPDs)**:

- Install **OCPDs** to prevent damage due to excessive currents, ensuring they comply with IEC 60947 standards.

➢ **Surge Protection Devices (SPDs)**:

- Install **surge protection devices** in compliance with **IEC 61643** to prevent damage from lightning or voltage spikes.

2.3 Technical Steps for Connecting (EV-FC) to Grid

■ **Grid Quality Management and Power Factor Control**

➢ **Voltage Fluctuations (IEC 61000-4-30)**: Ensure the **voltage** supplied to the charging station remains within acceptable limits to avoid excessive fluctuations that could harm the equipment or the grid. Use **voltage regulation devices** as needed to maintain stable voltage levels.

➢ **Power Factor (IEC 61000-3-2)**: Implement **power factor correction devices** to maintain an efficient power factor and prevent inefficient power consumption, reducing the risk of disturbances to the grid.

➢ **Harmonics and THD (Total Harmonic Distortion) (IEC 61000-4-7)**: Ensure that harmonic distortions from DC chargers remain within permissible limits according to **IEC 61000-4-7**. Use **harmonic filters** when necessary to reduce **THD** and avoid damage to the grid.

➢ **Reactive Power Management (IEC 61000-4-3)**: Install **reactive power compensation devices** to optimize system efficiency and prevent undue strain on the grid.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **Overcurrent & Surge Protection**
  - **Overcurrent Protection Devices (OCPDs)**: Install appropriate **OCPDs** to prevent damage from excessive currents ensuring compliance with IEC 60947 standards.
  - **Surge Protection Devices (SPDs)**: Install **surge protection devices** (in compliance with **IEC 61643**) to safeguard against voltage surges from lightning or grid switching events, ensuring the protection of charging infrastructure.
- **Monitoring and Control Systems**
  - **Energy Transfer Monitoring**: Ensure real-time monitoring of energy transfer and communication between **EVs and charging equipment** to ensure efficient operation.
  - **Continuous Safety Checks**: Implement systems to monitor **residual current**, **voltage levels**, and **charging conditions** during the entire process.
  - **Load Management**: Enable systems that manage **dynamic power limitations** based on **grid capacity** and **vehicle requirements**, ensuring that the system does not overload.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **Compliance with IEC 60364-7-722**
  - Follow **IEC 60364-7-722** for electrical installations related to EV charging:
    - Implement **automatic disconnection** of supply in case of faults or abnormal conditions.
    - Ensure **proper earthing** systems and protection against electric shocks.
    - Provide adequate shock protection, in line with IEC 60364-7-722 and IEC 61851-1, to safeguard against electric shock risks.
    - Provide shielding against **electromagnetic interference (EMI)** and **voltage disturbances to maintain safety and system integrity**.
- **Emergency Shutdown**
  - **Shutdown Protocols**: Implement **emergency shutdown systems** to disconnect power during faults or emergencies, ensuring safety for both users and infrastructure.
  - **Fail-Safe Mechanisms**: Ensure that the system enters **emergency shutdown mode** if communication is lost or a malfunction occurs, such as **vehicle disconnection during power flow**. **IEC 61851-25** outlines necessary emergency features for fail-safe operation.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- System Capacity and Load Balancing
  - Ensure the installation is designed to support **simultaneous charging** of multiple vehicles without overloading the system.
  - Implement **smart grid technologies** to improve **load balancing** between multiple charging stations, helping optimize grid capacity usage and reduce strain on the overall grid.
- Cooling Systems
  - For high-power DC chargers (e.g., those exceeding **200 kW**), ensure the infrastructure includes **adequate cooling systems** to manage **thermal loads** on cables and connectors during high-speed charging.
- Connector Standards
  - Ensure **DC chargers** are equipped with **CCS connectors** and meet the standards outlined in **IEC 62196**, ensuring compatibility with a wide range of electric vehicles.

2.3 Technical Steps for Connecting (EV-FC) to Grid

- **Grid Quality Issues (IEC Standards)**
  - **Voltage Fluctuations (IEC 61000-4-30)**: Ensure that the **voltage** supplied to the charging station is within acceptable limits, avoiding fluctuations that could harm equipment. Voltage regulation devices should be used when necessary.
  - **Power Factor (IEC 61000-3-2)**: Implement **power factor correction devices** to ensure efficient power usage and avoid disturbances to the grid.
  - **Harmonics and THD (IEC 61000-4-7)**: Ensure that harmonic distortions from DC chargers are within acceptable limits as specified by **IEC 61000-4-7**. Use **harmonic filters** when necessary to reduce **Total Harmonic Distortion (THD)** and avoid damage to the grid.
  - **Frequency Stability (IEC 61000-4-8)**: Monitor **grid frequency** within the limits specified by **IEC 61000-4-8** to ensure DC fast chargers operate effectively within frequency variations.
  - **Surge Protection (IEC 61643)**: Install **surge protection devices** (SPDs) in compliance with **IEC 61643** to protect the infrastructure from voltage surges due to external disturbances such as lightning strikes or grid switching events.
  - **Reactive Power (IEC 61000-4-3)**: Implement **reactive power compensation devices** to ensure efficient power consumption and reduce unnecessary strain on the grid.

3. Communication Protocols in IRVE Ecosystem

3.1 Overview of the IRVE Charging Ecosystem

- As these components work together, communication protocols are essential for interoperability, ensuring smooth coordination.
  - **EVs (Electric Vehicles)**: These are either fully electric (BEVs) or hybrid (PHEVs) and are charged via public or private charging stations (EVSEs).
  - **EVSEs (Electric Vehicle Supply Equipment)**: These control the charging process and can deliver either AC (slower) or DC (faster) power. Communication often happens via the **ISO 15118** protocol to ensure proper coordination.
  - **Charging Point Operator (CPO)**: CPOs manage the networks of EVSEs through cloud-based systems known as the **Charging Station Monitoring System (CSMS)**. This system monitors charging history, generates reports, runs diagnostics, schedules charging, and tracks real-time usage. The communication between EVSEs and CSMS typically uses the **OCPP (Open Charge Point Protocol)**.
  - **Distribution System Operator (DSO)**: DSOs oversee the distribution of energy from generation to consumers. In smart charging systems, they manage grid operations, handle network congestion, and address peak loads. They communicate available network capacity to CPOs or eMSPs (eMobility Service Providers) using the **Open Smart Charging Protocol (OSCP)**.
  - **eMobility Service Providers (eMSPs)**: eMSPs provide EV charging services to users, either via their own network or by collaborating with other networks for roaming access. Users subscribe to services (prepaid, postpaid, or group plans) to access public charging. Communication between CPOs and eMSPs typically uses protocols like **OICP**, **OCPI**, or **OCHP**.

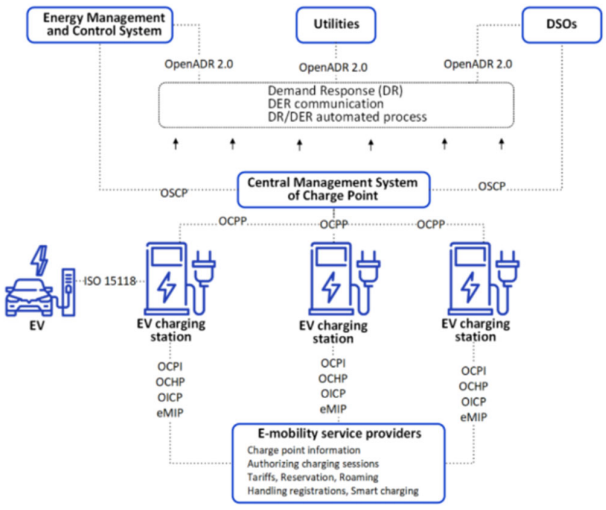
3.1 Overview of the IRVE Charging Ecosystem

- **Cloud Services**: EVSEs may connect to cloud platforms such as **AWS** or **Microsoft Azure** to exchange data. The specific protocols used are selected based on the security needs and technical requirements.
- **Original Equipment Manufacturers (OEMs)**: OEMs are responsible for manufacturing both EVs and EVSEs. They ensure distribution and might also offer additional services, such as post-purchase firmware updates.

- As all these components work together, communication protocols are vital to ensure smooth coordination and interoperability. The next section will delve into the key protocols that support these connections.

3.2 Overview of Standardization in IRVE

- **E-Mobility Systems Architecture (EMSA):**The **EMSA** model breaks down standardization into six functional areas that define how the system components work together:
  - **Communication with End-User Devices via REST-API**: This allows users to interact with charging stations through apps or in-car systems, enabling features like station location, status checking, and session management.
  - **EV Charging & Automatic Authorization (e.g., IEC/ISO 15118)**: Protocols like **IEC/ISO 15118** enable automated authorization, allowing for secure, hands-off charging with features like **Plug & Charge**, which eliminates the need for manual authentication.



Communication standards for the electric vehicle charging infrastructure

Source: Cyber Security of Electric Vehicle Charging Infrastructure: Open Issues and Recommendations, Inna S. et al. 2022

3.2 Overview of Standardization in IRVE

- Standardization is critical in the **EV charging ecosystem** to ensure seamless communication and compatibility across various systems. Standards from **ISO/IEC** and **SAE** focus on four main areas: charging connectors, communication protocols, charging topology, and safety.
- **Key Areas of Standardization**
  - **Charging Connectors**: These standards define the physical plugs used for EV charging, ensuring that vehicles and charging stations are universally compatible.
  - **Charging Communication**: This area covers how data is exchanged between EVs, charging stations, and backend systems, allowing for efficient charging operations, billing, and grid integration.
  - **Charging Topology**: Refers to the architecture of the charging network, including station placement and how they interact with each other and the grid. Standardized topology ensures scalability and consistency in the network.
  - **Safety**: Safety standards are in place to ensure that all charging components operate without risk, covering everything from electrical safety to user protection.

3.2 Overview of Standardization in IRVE

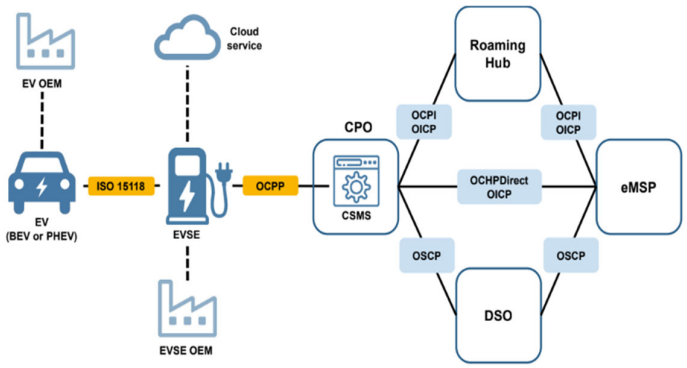
- **Management of Charging Stations (e.g., OCPP)**: **OCPP (Open Charge Point Protocol)** is used for the remote management and monitoring of charging stations, allowing operators to manage the stations, schedule charges, and troubleshoot remotely
- **Information Exchange Between Charging Station Operators (CSO) and E-Mobility Service Providers (eMSP) (e.g., OCPI)**: **OCPI (Open Charge Point Interface)** allows for the exchange of operational and billing data between charging station operators and eMSPs, facilitating smooth service across different networks.
- **Roaming (e.g., OCHP, OICP)**: Roaming protocols like **OCHP** and **OICP** enable users to access chargers across different service provider networks, expanding the availability of charging stations through roaming agreements.
- **Communication with Grid Operators (e.g., OSCP)**: The **Open Smart Charging Protocol (OSCP)** allows for communication between charging stations and grid operators, enabling smart grid functionality like demand response, load balancing, and grid stability.

3.3 Architecture of a Smart Charging System

- A **smart charging system** integrates various components that work together to manage energy distribution and offer seamless services to **EV drivers**. It relies on two primary interfaces to operate effectively:
  - **Electricity Distribution Interface:** This interface controls the flow of electricity from the grid to the **EVs**, ensuring that **charging stations** deliver power efficiently and effectively. It helps manage grid resources and prevent overloads by distributing electricity based on real-time demand.
  - **Control Interface for Status, Authorization, Metering, and Billing:** This interface is responsible for
    - **Tracking the charging session** (start/stop times, power usage, etc.).
    - **User authorization** (ensuring only authorized users can access the station).
    - **Metering energy usage** to determine the amount of power used.
    - **Billing** by calculating and processing the cost based on energy consumed during the charging session.

3.3 Architecture of a Smart Charging System

- **Role of Interoperable Standards and Protocols**
  - The seamless operation of these interfaces relies on standards and communication protocols. These ensure that all components—charging stations, vehicles, backend systems, and grid operators—can work together without compatibility issues.
- **Dynamic Algorithms for Grid Optimization**
  - Incorporating **adaptive algorithms** allows the system to dynamically adjust charging power levels. This adjustment is based on real-time **grid conditions** and helps **optimize energy distribution**, especially during periods of high demand. This helps **reduce grid overloads** and contributes to more efficient energy usage



Smart charging System Architecture

Source: Smart and secure EV Charging with NXP secure solutions, AN13645, 2022

3.4 Communication Protocols in the IRVE Ecosystem

- Communication protocols play a vital role in ensuring smooth and compatible data exchange between different systems in the **IRVE (Infrastructure for Rechargeable Vehicles)** ecosystem. With the rising adoption of electric vehicles (EVs), it's crucial to ensure effective coordination between the mobility and energy sectors. By exchanging data such as car identification, battery status, and energy requirements, EVs can be efficiently integrated into the grid, helping manage peak electricity demand and optimizing the charging process.
- **Security** is a central concern in the communication between these systems, covering both front-end and back-end protocols like **ISO 15118**, **OCPP**, **OpenADR**, **IEEE 2030.5**, and **EEBus**. These protocols ensure that communication is secure and that the smart charging ecosystem remains reliable and protected.
- **Front-End Protocols:** Front-end protocols deal with communication between **Electric Vehicles (EVs)** and **EV charging stations**. They handle the connection between the vehicle and the charger, managing aspects like plug types, charging methods, and ensuring both safety and security.

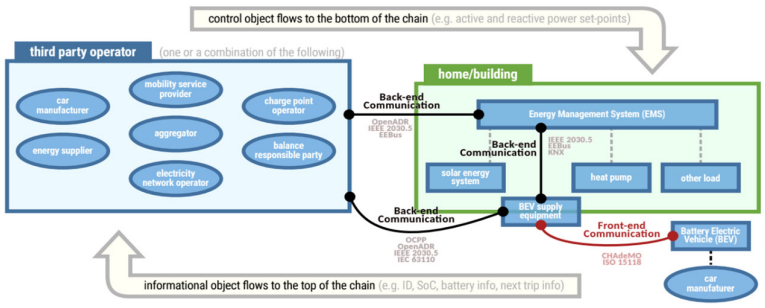
3.4 Communication Protocols in the IRVE Ecosystem

- **ISO 15118**: This protocol enables secure, bidirectional communication between the EV and the charging station. It supports features like **Plug & Charge**, which allows for easy authentication and billing.

Sections of ISO 15118

ISO 15118-1	Presents the overall flow of communication and general use cases
ISO 15118-2	Deals with the requirements of messages exchanged by EV and EVSE over the top 5 layers of the Open System Interconnection (OSI) model.
ISO 15118-3	Deals with the functionalities of the bottom 2 layers of the OSI model which are physical and data link layer requirements.
ISO 15118-4	Includes the conformance tests for ISO 15118-2 only which deals with layers 3 and up and does not consider the power flow between EV and EVSE.

Source: DOI: 10.5121/ijcsit.2024.16101



Various EV Ecosystem Entities Connected by Communication Protocols

Source: https://energyinformatics.springeropen.com/articles/10.1186/s42162-020-0103-1

3.4 Communication Protocols in the IRVE Ecosystem

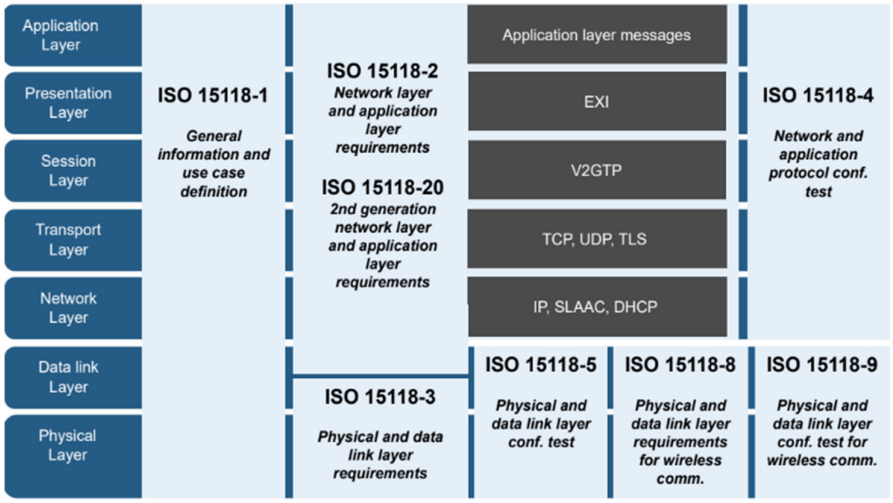
- **IEEE 2030.5**: This standard focuses on **smart grid communication** and energy management, primarily in **home area networks** and **Vehicle-to-Grid (V2G)** ecosystems. It uses **lifetime certificates** for security but lacks a **Public Key Infrastructure (PKI)**, making it more suitable for smaller-scale environments like homes rather than large-scale infrastructure.
- **EEBus**: Used for communication between electric devices (such as EVs) and the **smart grid** in home or building settings. It focuses on **IoT communication** and uses secure protocols like Transport Layer Security **(TLS)** in the **SHIP (network layer)** for secure communication. EEBus is useful when paired with **SHIP** for secure interactions in EV charging infrastructure.
- **CHAdeMO**: A communication protocol for **Vehicle-to-Grid (V2G)** functionality, CHAdeMO enables direct communication between the EV and the charging station. It also developed **ChaoJi**, an advanced ultra-fast charging standard in collaboration with the China Electricity Council (CEC), aligned with **China's GB/T charging protocols**.

3.4 Communication Protocols in the IRVE Ecosystem

- **Back-End Protocols :**Back-end protocols manage communication between the **EV charging stations** and central management systems (CMS). They typically handle charging management, billing, and data exchange between charging infrastructure and central systems.
  - **OCPP (Open Charge Point Protocol)**: This is the most widely used back-end protocol, managing the interaction between EVSEs (Electric Vehicle Supply Equipment) and **central systems** like **Charging Station Monitoring Systems (CSMS)**. It enables efficient network management, ensures secure communication via **TLS encryption**, and integrates with **ISO 15118** for additional functionality.
  - **IEC 61851-23:2014 and IEC 61851-24:2014**: These standards focus on **charging operations** and the **digital communication** between the vehicle and charger, supporting efficient and secure charging infrastructure management.
  - **OpenADR**: In the back-end, OpenADR facilitates **demand response** in distributed energy resources (DERs). It uses **TLS encryption** and Public Key Infrastructure **(PKI)** for secure messaging and authentication. OpenADR and **IEEE 2030.5** complement each other in networked environments, enhancing overall system security and communication.

3.5 ISO 15118 Protocol

- **ISO 15118 Protocol: Enhancing Security and Interoperability in IRVE Integration**
  - **ISO 15118** is a critical **front-end protocol** that connects **Electric Vehicles (EVs)** with the **charging infrastructure**, playing a pivotal role in ensuring smooth communication between the vehicle, the charging station (IRVE), and the central management system (CMS).



ISO 15118 Protocol Stack and How the Different Parts of the Standard Map.

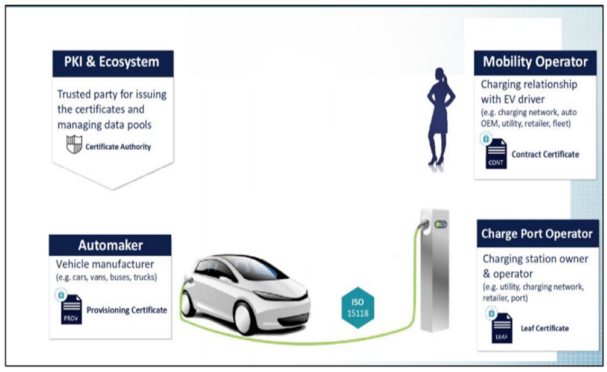
Source: Smart and secure EV Charging with NXP secure solutions, AN13645, 2022

3.5 ISO 15118 Protocol

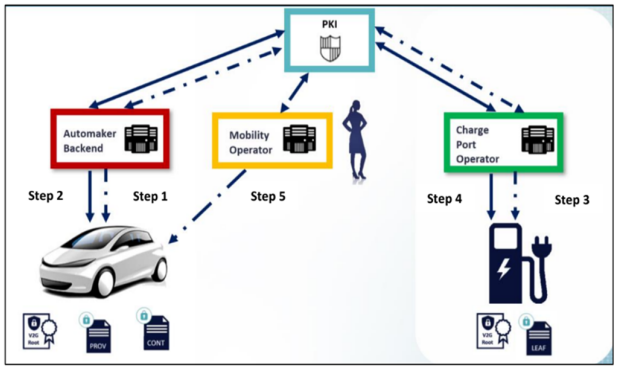
- **Key Functions of ISO 15118:**
  - **Grid Integration and Control**: ISO 15118 enhances **charging efficiency** by facilitating real-time monitoring and control, which is crucial for managing **energy distribution** and **grid stability** during EV charging sessions.
  - **Communication Framework**: The protocol uses **Power-Line Communication (PLC)** to establish communication between the EV and the **IRVE**, and **Ethernet with IPv6 UDP/TCP** alongside **Open Charge Point Protocol (OCPP)** for secure communication between the **EVSE** and **CMS**.
  - **Security Features**: One of the standout features of ISO 15118 is its strong focus on **security**. It standardizes communication protocols to protect EV charging systems, safeguarding user data and ensuring secure transactions.
- **Key Features of ISO 15118:**
  - **Plug & Charge (PnC)**: Enables **touchless charging** with **automatic vehicle authentication** using **digital certificates**, eliminating the need for cards or apps.
  - **Smart Charging**: Supports **two-way communication** for **optimized energy use** and **grid stability**.
  - **Vehicle-to-Grid (V2G)**: Allows **energy exchange** between the vehicle and the grid, supporting **energy storage** and **demand management**.
  - **Wireless Charging**: Supports **wireless charging** for **autonomous vehicles**, eliminating the need for physical connectors.

3.5.1 PKI and Digital Certificates

- ISO 15118 uses **Public Key Infrastructure (PKI):**
  - To manage **digital certificates** for secure communication. This infrastructure ensures that the **EV**, **IRVE**, **charge point operators (CPO)**, and **mobility operators (MO)** can authenticate each other, enabling secure data exchange and **safe transactions**.
  - PKI ensures secure communication within the Vehicle-to-Grid (V2G) ecosystem, similar to its use on the internet for secure messaging, document signing, and user authentication. It supports secure communication in protocols such as ISO 15118-20, OCPP 2.0, and OpenADR.



PnC Stakeholders and Their Associated Certificates



Stakeholder Connections and Certificates in a Charging Session

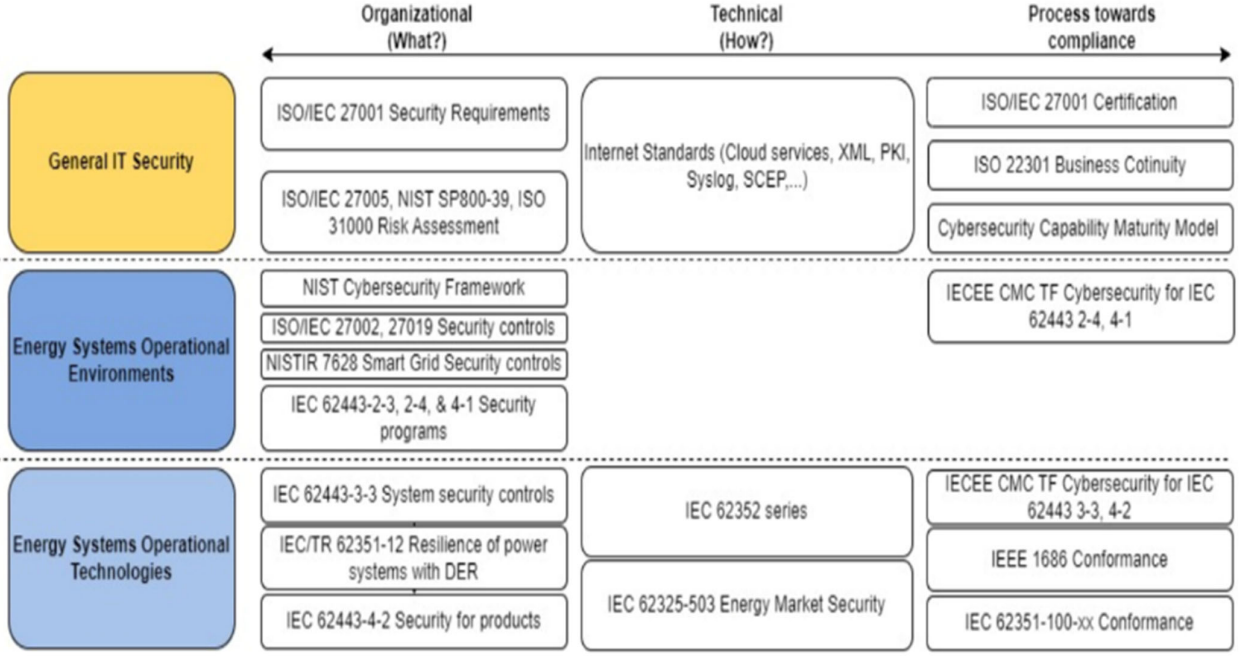
Source: Electric Vehicle Charging Open Payment Framework with ISO 15118, Secure Technology Alliance, 2021

4. Cybersecurity in IRVE: Securing the Infrastructure

4.1 Cybersecurity Standards in the Energy Sector

- The increasing complexity of **smart grids** and the variety of assets they involve make **cybersecurity standards** essential for safeguarding the sector. These standards help address different security needs, control measures, and technological solutions.
- **Purpose of Standards:**
  - **High-Level Security Requirements**: Some standards focus on what needs to be secured, providing broad guidelines for **organizational security** and identifying critical assets or systems that require protection.
  - **Technical Implementation**: Other standards outline the **specific methods** and **technical controls** for applying security measures, detailing **how** security should be implemented across systems and technologies.
- **Categories of Standards:**
  - Cybersecurity standards in the energy sector are organized based on their specific function, offering **structured guidelines** for securing both **organizational** and **technical** aspects. These categories ensure a comprehensive approach to protecting the infrastructure.

4.1 Cybersecurity Standards in the Energy Sector



Cybersecurity standards and Guidelines that apply to smart energy operational environments.

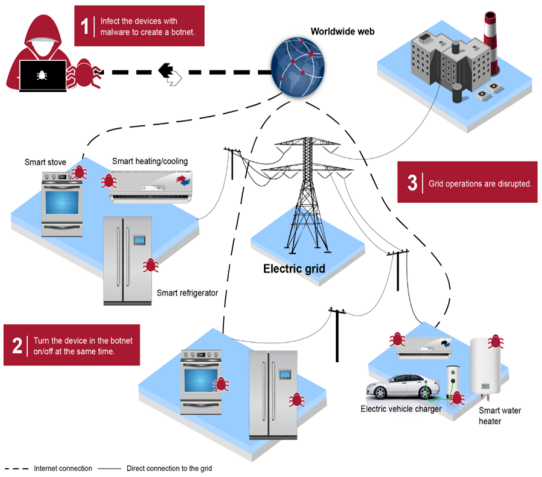
Source: Cybersecurity requirements for Grid Operators, D4.4, One Network for Europe, Magda Z. et. al. 2023

4.2 Cybersecurity: Real-World Risks to Grid Stability

- As **grid distribution systems** become more interconnected with **consumer devices**, their exposure to **cyberattacks** increases. Compromised devices can manipulate grid operations, putting **power stability** at risk.
- **Impact on Grid Operations:**
  - **Manipulation of Electricity Demand**: Cyberattacks can alter **electricity demand**, either by increasing or decreasing it, causing significant disruption in **grid operations**.
  - **Threat to Grid Stability**: Such attacks have the potential to **severely impact** grid stability, leading to **widespread power disruptions** and unreliable service.
  - **Power Grid Informatics**: This refers to managing information within **cyber-physical systems** of the power grid, encompassing how data is **stored**, **processed**, and **communicated**.
  - **Cyber-Physical System Interactions**: The connection between the **physical power grid systems** and their **cyber counterparts** is vital. This includes **algorithms**, system behavior, and the way **humans interact** with grid information, all of which can be vulnerable to attacks.

4.3 Cyber-Physical Components in Grid Systems

- **Cyber-Physical Components in Grid Systems**
  - The interactions between **physical power grid systems** and their corresponding **cyber systems** are crucial for the overall operation. These interactions involve **algorithms**, **system behaviors**, and **human interactions** with **grid information**.



Example of an Attacker Compromising High-Wattage Networked Consumer Devices

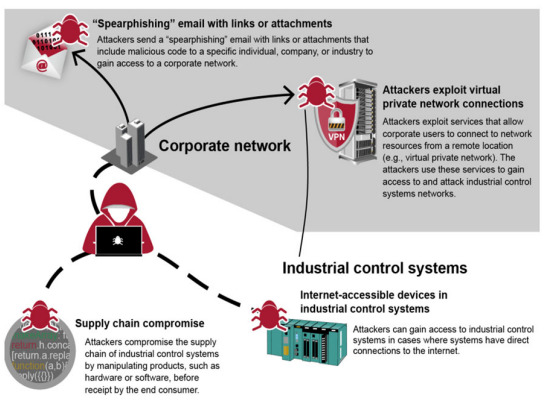
Source: GAO analysis of industry and federal documents. GAO-21-81

4.3 Cyber-Physical Components in Grid Systems

- **Key Components:**
  - **Power Grid Utility**: The utility relies on **cloud computing** and **storage systems** to manage vast amounts of data and ensure **grid services** run smoothly and efficiently.
  - **Electric Vehicle (EV)**: EVs use **mobile smart meters** and **sensors** to track **energy usage** and monitor **vehicle functions**, providing real-time data to both the user and the grid.
  - **External Services**: These services include **infrastructure** and **data management systems** that support grid operations, ensuring efficient communication and control across devices.
    - **Cybersecurity Risks**: Devices like **smart meters** are vulnerable to compromise. **Malicious actors** could hijack these **high-wattage devices** to create a **botnet** capable of launching coordinated **cyberattacks**, jeopardizing both grid stability and security.

4.4 Cybersecurity Risks in the IRVE Ecosystem

- A **security breach** in the **EV ecosystem** can have far-reaching effects, impacting both the **energy sector** and **national infrastructure**, leading to disruptions in daily life and posing **national security** risks.
- The widespread use of **sensors** in **electric vehicles (EVs)** has introduced significant **cybersecurity threats** and **privacy concerns** due to the sensitive data these sensors collect.



Examples of Techniques for Gaining Initial Access to Industrial Control Systems

Source: GAO analysis of industry and federal documents. GAO-21-81

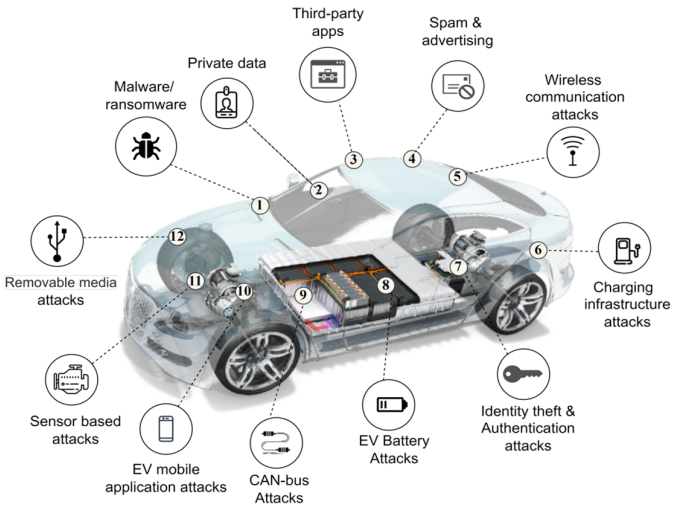


Illustration of security threats and cyberattacks targeting EVs.

Source: Doi.org/10.3390/en16031113

4.4 Cybersecurity Risks in the IRVE Ecosystem

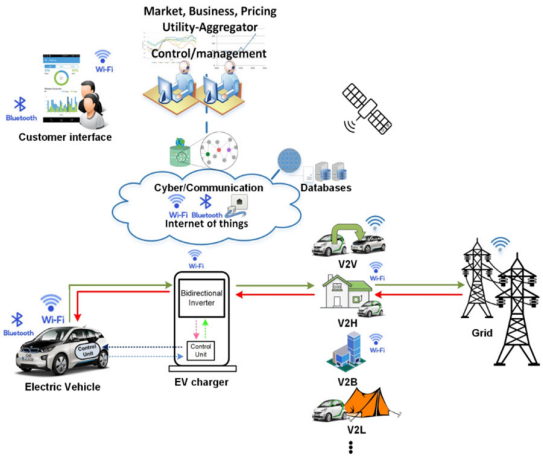
- **Sensitive Data at Risk**:
  - **Personal data** such as **driver identity**, **location**, and **vehicle performance** are collected by EV sensors, putting **privacy** at risk.
  - The **EV ecosystem** exchanges **sensitive data** like **user information**, **vehicle data**, and **payment details**, all of which can be exploited by **cybercriminals** for **malicious purposes**.
- **Vulnerabilities in Vehicle Systems**:
  - **Software vulnerabilities** within EVs can be targeted by attackers to gain **unauthorized access** to vehicle systems.
  - In extreme cases, **cybercriminals** could gain control of the vehicle, posing severe **safety risks** to drivers and passengers.
- **Categories of Cyber Threats**:
  - There are **twelve categories** of cyber threats, each with the potential to compromise the **security** of **vehicle owners** and **manufacturers**, ranging from data breaches to control system exploits.

4.5 Cybersecurity Threats in the IRVE Ecosystem

- The rise of **smart and fast charging systems** for electric vehicles (EVs) brings new **cybersecurity challenges** that could compromise **grid stability**, **personal data**, and even **vehicle integrity**. Addressing these threats is crucial as the **EV ecosystem** continues to evolve.
- **Key Cybersecurity Threats:**
  - **Demand Manipulation**: Cyber attackers can influence **charging demand**, creating imbalances that affect both **system efficiency** and **grid performance**.
  - **Man-in-the-Middle (MITM) Attacks**: Cybercriminals intercept and modify communications between **EVs** and **charging stations**, leading to **operational disruptions** and potential **grid overloads**.
  - **Denial of Service (DoS)**: Attackers block access to charging services, preventing **users** (including **emergency vehicles**) from charging, with significant operational and societal consequences.
  - **Distributed Denial of Service (DDoS)**: A large-scale version of DoS, where multiple **charging stations** are targeted, disrupting **EV charging** and affecting **traffic flow**.
  - **Denial-of-Charge (V2G specific)**: This attack targets **vehicle-to-grid** systems, preventing **EVs** from charging, especially during **critical situations**, such as emergencies.

4.5 Cybersecurity Threats in the IRVE Ecosystem

- **Malware**: Malicious software infiltrates **charging stations**, **stealing data** or manipulating charging operations, compromising the integrity of both **vehicles** and **stations**.
- **Two-Way Power Flow Attack**: **Compromised vehicles** can overload the grid by demanding or supplying power at inappropriate times, posing **public safety risks** and threatening **grid stability**.
- **False Data Injection Attacks (FDIA)**: Cyber attackers manipulate **data** such as energy requests or usage, leading to issues like **battery damage**, **overcharging**, or grid disruptions.



Cyber-Physical-Social Systems structure of V2X

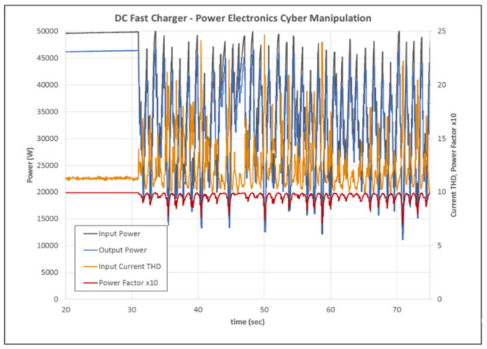
Source: doi.org/10.1145/3590777.3591406

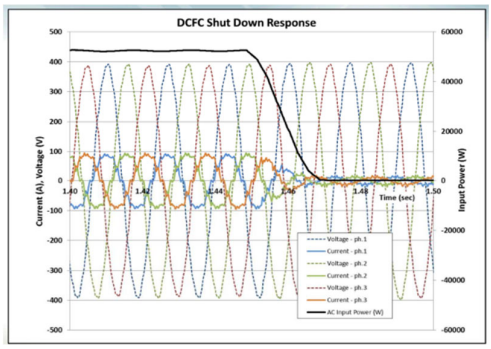
4.6 Cybersecurity Threats to Grid Stability

- **Vulnerable IRVE**: Cyberattacks on vulnerable **IRVE** interfaces such as internal ports, communication links, user access points, wireless connections, and cloud services can disrupt IRVE operations and affect grid stability.
- **Grid Impact of Cyberattacks**:
  - **Power Quality Issues**: Cyberattacks can increase **Total Harmonic Distortion (THD)** and lower the **power factor**, leading to **grid instability**.
  - **Emergency Stops and Power Drops**: Attacks may trigger **sudden shutdowns**, destabilizing charging stations and impacting the grid.
  - **Man-in-the-Middle (MITM) Attacks**: Cybercriminals can intercept and manipulate communications to steal energy or disrupt grid operations.
- **Coordinated Load Manipulation**: Cyberattacks may manipulate **large groups of EV chargers**, pushing the power system beyond its limits, potentially causing:
  - **Undervoltage**,
  - **Overloaded transmission lines**, and
  - **Outages**. Such manipulations can destabilize both **distribution** and **transmission** networks.
- **Impact of EV Charging on Grid Stability**: While **isolated charging** typically doesn't affect grid stability, **massive coordinated charging** (or **V2G operations**) could lead to:
  - **Voltage instability**,
  - **Power quality issues**, and
  - **Reliability problems**.
- **Dynamic Load Modulation Risks**: Attackers exploiting vulnerabilities in **EVSE systems** could **dynamically modulate charging loads**, pushing **grid frequencies** beyond safe limits, which could destabilize the power grid.

4.6 Cybersecurity Threats to Grid Stability

- **DC Fast Charging (DCFC)** systems, introduce several **cybersecurity risks** that can directly affect **grid stability**.
  - These occur when all **power electronics modules** in a **DCFC system** shut off simultaneously, creating significant power changes. The impacts include:
- **Risks to Grid Stability from High-Powered Chargers**:
  - DCFC systems can go from delivering **full power** (e.g., **50 kW**) to **standby power** (~300W) in just **0.020 seconds**, causing a rapid power change of **-2.6 MW/sec**.
  - **Multiple DCFC systems shutting down** at once could lead to **larger disturbances**, potentially compromising grid stability.
  - The impact of shutdowns is more significant with **higher capacity chargers** (e.g., **350 kW XFC** systems).
  - **Multiple high-powered chargers** shutting down simultaneously could pose serious risks to **grid stability**.



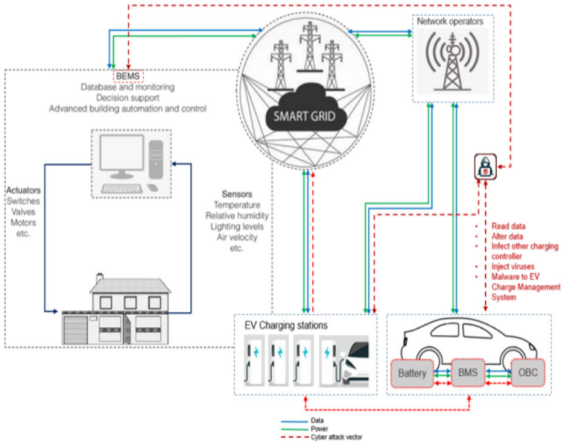


Source: Cyber Security of DC Fast Charging: Potential Impacts to the Electric Grid, INL, Kenneth Rohde, 2019

4.7 Cybersecurity Risks in IRVE Data Flow

- The integration of **Electric Vehicles (EVs)** into the power grid through **Advanced Metering Infrastructure (AMI)** networks introduces cybersecurity vulnerabilities. These systems, designed to collect and manage data from **smart meters**, can be targeted by malicious actors.

- **Key Cybersecurity Risks:**
  - **Smart Meter Infiltration**: Attackers could physically compromise **smart meters**, gaining unauthorized access to the **AMI network**. This might involve exploiting weak cryptographic protections or manipulating meter synchronization.
  - **Unauthorized Device Insertion**: By understanding meter communication and synchronization, attackers may insert **unauthorized devices** into the network, potentially gaining control and introducing new vulnerabilities.



Typical Smart City IRVE Data Flow

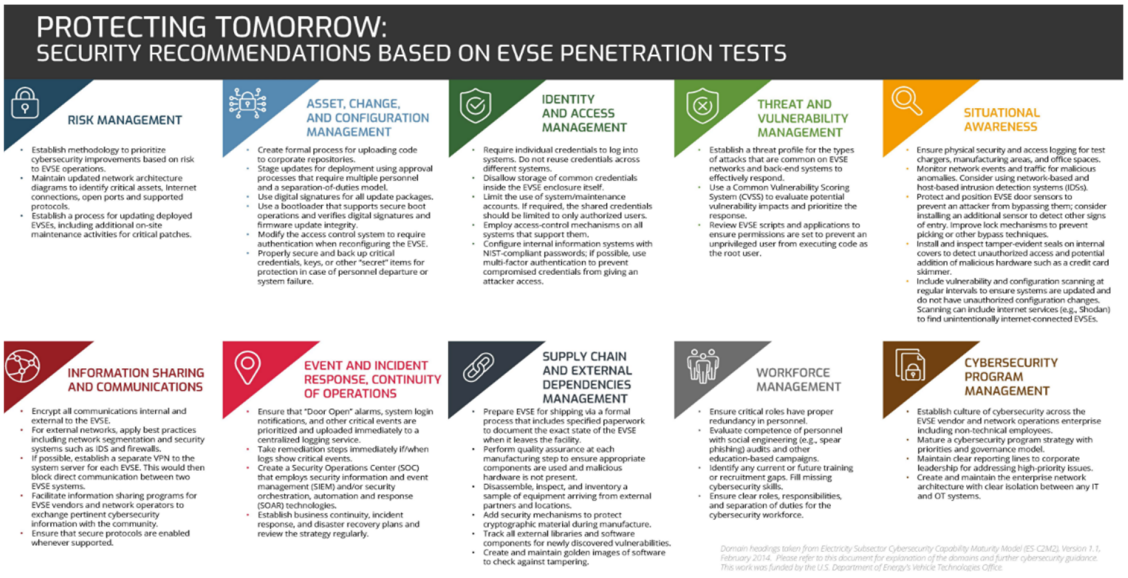
Source: Cyber Security of Electric Vehicle Charging Infrastructure: Open Issues and Recommendations, Inna S. et al. 2022

4.7 Cybersecurity Risks in IRVE Data Flow

- **Meter Worm Attacks**: Once inside the network, attackers can deploy a **Meter Worm**, remotely controlling multiple meters to **shut them off simultaneously**, causing rapid power cycling. This could destabilize the grid, similar to the **Aurora attack**, which targeted power infrastructure.
- **AMI Head End Targeting**: The **AMI Head End**, responsible for controlling and communicating with all smart meters, is a critical target. If compromised, it could manipulate the entire network, leading to **fluctuations in power**, **grid instability**, and severe **infrastructure damage**.

4.8 Enhancing Cybersecurity for IRVE and Power Grid

- While the energy sector focused on physical security in the past, it now needs to enhance its cybersecurity to match industries like finance, as digital technologies become more integrated.



Source: Domain headings taken from Electricity Subsector Maturity Model (ES C2M2) Version 1.1, February 2014, this work was funded by the US Department of Energy/Vehicle Technology Office.

4.8 Enhancing Cybersecurity for IRVE and Power Grid

- **NREL Guidelines:** The **National Renewable Energy Laboratory (NREL)** highlights cybersecurity risks specific to **EV charging infrastructure**, stressing vulnerabilities that need attention.

- **ENISA Guidelines:** The **European Union Agency for Cybersecurity (ENISA)** offers best practices for **Distribution System Operators (DSOs)**. Key recommendations include:
  - **Risk Management**: Identify, assess, and mitigate risks effectively.
  - **Security-Aware Culture**: Foster a culture of security awareness among employees and stakeholders.
  - **Asset Control**: Properly manage and protect assets.
  - **Incident Response**: Develop strong strategies for responding to cybersecurity incidents.



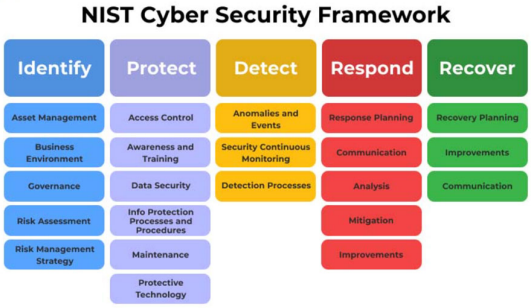
ENISA's risk management guidelines for the electricity subsector.

Source: Cybersecurity requirements for Grid Operators, D4.4, One Network for Europe, Magda Z. et. al. 2023

4.8 Enhancing Cybersecurity for IRVE and Power Grid

- **NIST Framework:** The **National Institute of Standards and Technology (NIST)** provides frameworks that assist **electricity sector stakeholders** in enhancing their **cybersecurity strategies**.

  - The **NIST Cybersecurity Framework (CSF)** provides a structured approach for organizations to manage cybersecurity risks. It aligns with industry standards and helps in identifying and addressing risks based on an organization's maturity level.
  - To assess risks, focus on the core principles of confidentiality, integrity, and availability. Tools like **STRIDE**, a threat modeling technique, assist in evaluating potential risks and threats across various attack vectors, helping to proactively identify vulnerabilities.





Source: Domain headings taken from Electricity Subsector Maturity Model (ES C2M2) Version 1.1, February 2014, this work was funded by the US Department of Energy/Vehicle Technology Office.

4.8 Enhancing Cybersecurity for IRVE and Power Grid

- To mitigate cybersecurity risks for **IRVE charging infrastructure**, comprehensive strategies are essential. The **NIST Cybersecurity Framework** offers crucial guidelines for securing cloud services like **IaaS**, **PaaS**, and **SaaS**, and can be applied to EV charging systems.
- The framework consists of five key functions:
  - **Identify**: Understand and assess risks to critical systems.
  - **Protect**: Implement preventive measures to secure infrastructure.
  - **Detect**: Quickly identify security breaches or suspicious activity.
  - **Respond**: Take immediate action to reduce the impact of threats.
  - **Recover**: Restore services quickly to minimize downtime.

Function	Function Unique Identifier	Category	Category Unique Identifier
IDENTIFY	ID	Asset Management	ID.AM
		Business Environment	ID.BE
		Governance	ID.GV
		Risk Assessment	ID.RA
		Risk Management Strategy	ID.RM
		Supply Chain Risk Management	ID.SC
PROTECT	PR	Access Control	PR.AC
		Awareness and Training	PR.AT
		Data Security	PR.DS
		Information Protection Processes and Procedures	PR.IP
		Maintenance	PR.MA
		Protective Technology	PR.PT
DETECT	DE	Anomalies and Events	DE.AE
		Security Continuous Monitoring	DE.CM
		Detection Processes	DE.DP
RESPOND	RS	Response Planning	RS.RP
		Communications	RS.CO
		Analysis	RS.AN
		Mitigation	RS.MI
		Improvements	RS.IM
RECOVER	RC	Recovery Planning	RC.RP
		Improvements	RC.IM
		Communications	RC.CO

NIST five functions framework core categories

Source: DOI: 10.5121/ijcsit.2024.16101

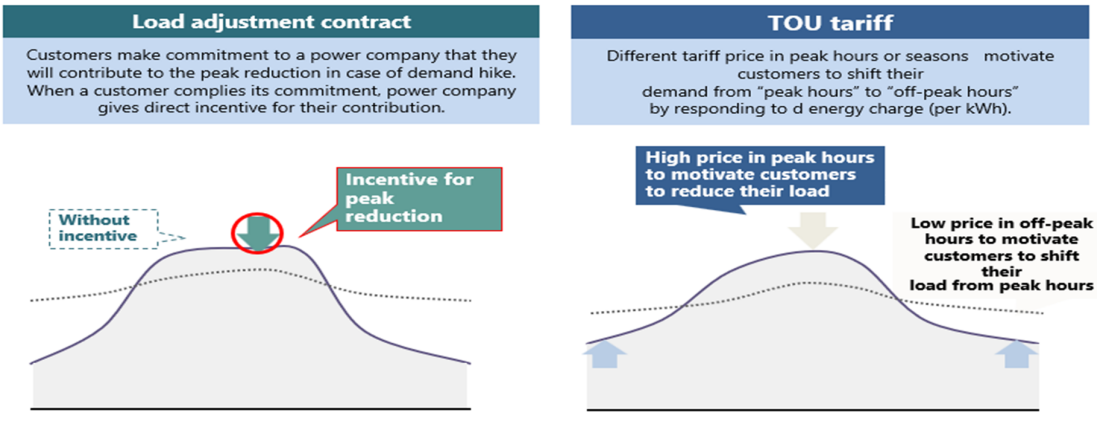
5. Introduction of Japan's Experience on DSM

5.1 Necessity of Promoting DSM

- DSM (Demand Side Management) provides various incentives to users in exchange for shifting electricity demand from peak to off-peak periods (load shifting), thereby improving supply and demand of the entire power system and improving the efficiency of power supply through load levelling.
- In particular, there was a growing awareness, particularly in developed countries, to control energy supply costs, and this led to a growing interest in peak shifting and load levelling by DSM.
- The main purpose of DSM is to restrain capital investment for increasing the capacity of energy supply by adjusting the time of energy consumption and using storage and to improve the economic efficiency of energy supply by levelling and smoothing its fluctuations.

5.1 Necessity of Promoting DSM

- The demand side control mechanisms can be classified in roughly two types :
  - load adjustment contract and
  - Time of Use (TOU) tariff system.
- Load adjustment contract is to provide **direct incentive for peak cut/shift** to the customer.
- TOU tariff is to motivate customers to **voluntary peak cut/shift** with price signals.



Rate Incentives for DSM: Supply/demand adjustment agreements and time-of-day rates

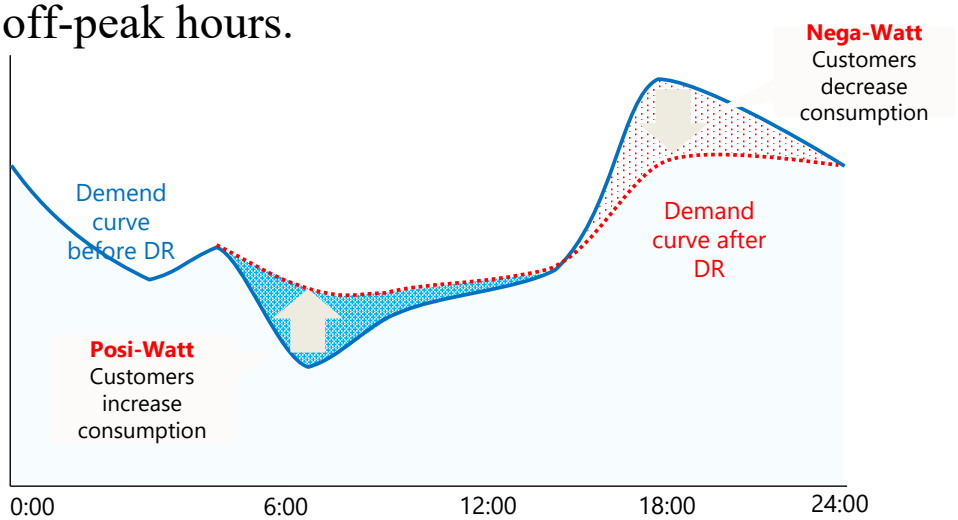
Source: JICA consultants

5.1 Necessity of Promoting DSM

- As shown in Figure, there are two major types of DSM rate incentives offered by Japanese power companies: supply and demand adjustment contracts and time-of-use (TOU) rates.
- Supply and demand adjustment contracts specifically commit to how much load levelling, such as peak cutting, can be done, and power companies provide direct incentives for doing so.
- On the other hand, time-of-day rates provide a price menu with different unit prices during peak and off-peak hours, and motivate consumers to voluntarily level their load through price signals.
- Therefore, in response to an unexpected increase in demand across the entire system, they were required to maintain the balance between supply and demand through the provision of supply reserves or the suppression of demand, but this duty was borne by the power company.
- In addition, in order to stabilize the system frequency, it was necessary to maintain the balance between supply and demand even in periods shorter than 30 minute increments, which was also a one-sided responsibility of the power company.

5.2 New Role Expected of DSM

- Against this backdrop, the regional power companies offered various types of DSM rate programs to consumers in order to control peak demand and to level the load.
- In addition to load levelling by suppressing demand during peak hours, there is a growing expectation of load levelling by raising demand during off-peak hours.



Rate Incentives for DSM: Supply/demand adjustment agreements and time-of-day rates

Source: JICA consultants

5.2 New Role Expected of DSM

- It is expected to **utilize Demand Response (DR) in more varied ways,** not only in cases of severe supply/demand imbalance, but **also in normal circumstances** to maintain supply/demand balance and improve efficiency of power generation.
- This type of DR could be characterized as **market-oriented measure**, as it is more based **on customers' motivation to gain incentives** for trading not only nega-watt but also posi-watt.
- DR can contribute to further deployment of renewable energy sources.
  - Power generation by renewable energy such as PV and wind power fluctuates in large extent depending on the weather condition. It will cause excess supply.
  - In such case, **DR will enable demand creation (posi-watt) in order to utilize the excessive energy generated by renewable power plants**, for example, charging battery storage systems.
- DSM measures are expected to contribute to the stabilization of power supply and demand in terms of both negative and positive watts.

5.2 New Role Expected of DSM

- In recent years, solutions to provide positive watts by charging energy storage systems such as storage batteries and negative watts by discharging them during peak hours have also attracted attention, and it is expected that load levelling by DSM will play a greater role as the cost of energy storage systems decreases in the future.

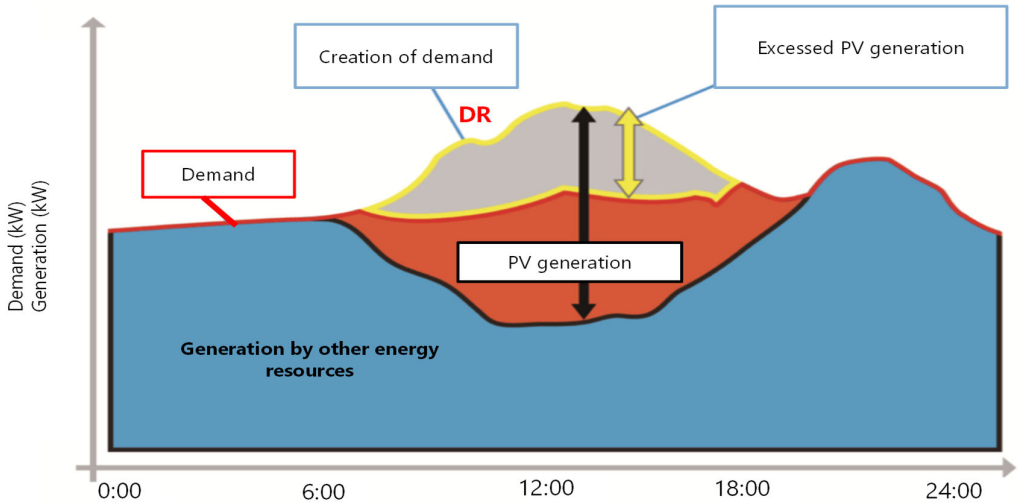


Figure: Absorption of excess solar power by DR (positive watt) (red line to yellow line)

Source: METI Website
(https://www.meti.go.jp/committee/kenkyukai/energy_environment/energy_resource/pdf/006_08_00.pdf)

5.3 Trend in (DSM): Advanced (DR) through (VPP).

- VPP (Virtual Power Plant) is a recently developed technology that aggregates the distributed energy resources (DERs) such as on-site generators, energy storage and consumers' device, and controls them to serve like a single power generation unit, making use of information and communication technology (ICT).

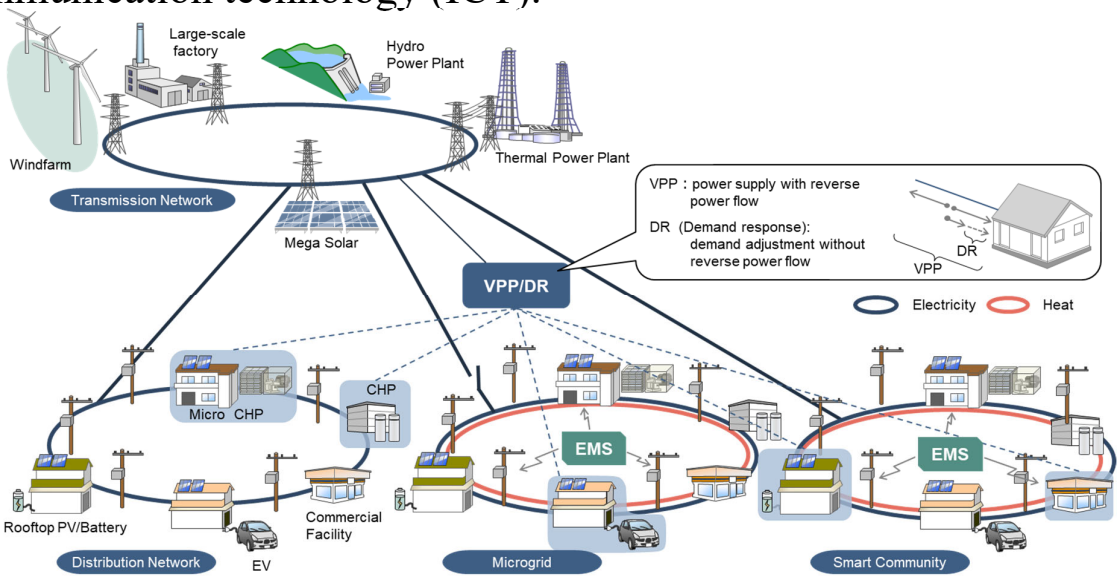


Figure: Concept of VPP

Source: METI "VPP／EV Aggregation Project" (https://www.nedo.go.jp/content/100898203.pdf)

5.3 Trend in (DSM): Advanced (DR) through (VPP).

- Virtual Power Plant (VPP) is a technology that provides the same power supply function as a large-scale power plant by controlling power demand (demand response) and demand-side energy resources such as in-house power generation facilities and storage facilities connected to the power system (including reverse flow from the demand-side energy resources to the system).
- Although it does not supply electricity to the power system, demand response (DR) provides the same value by changing power demand as the resulting power generation facilities change output.
- A business that uses VPP and DR to provide services such as adjusting power, avoiding imbalances, reducing electricity rates, and avoiding output suppression to general electricity transmission and distribution companies, retail electricity companies, consumers, and renewable energy power generation companies is called energy resource aggregation business (ERAB: Energy Resource Aggregation Businesses).

5.3 Trend in (DSM): Advanced (DR) through (VPP).

- In Japan, such a business that provides VPP and DR services is being studied on the assumption that it will consist of two tiers of operators: resource aggregators and aggregation coordinators.

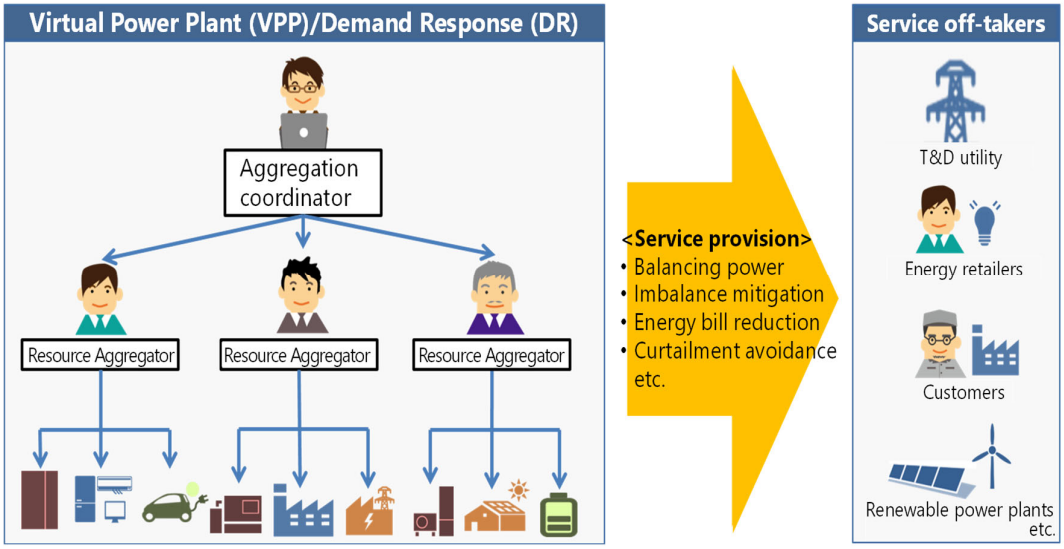


Figure: Energy Resource Aggregation Business

Source: Agency for Natural Resources and Energy

5.3 Trend in (DSM): Advanced (DR) through (VPP).

- A resource aggregator is an operator that controls resources by entering into VPP service agreements directly with consumers, while an aggregation coordinator is an operator that bundles up the amount of electricity controlled by the resource aggregator and deals with general transmission and distribution operators and retail electric utilities.

5.4 Integrating V2G with DSM for Grid Stability

- The utility of Vehicle-to-Grid (V2G), a technology for supplying stored electric power to the grid, is attracting attention, in addition to shifting EV charging demand to contribute to the stabilization of supply and demand by controlling EV on-board storage batteries connected to the power system via chargers from the grid side.

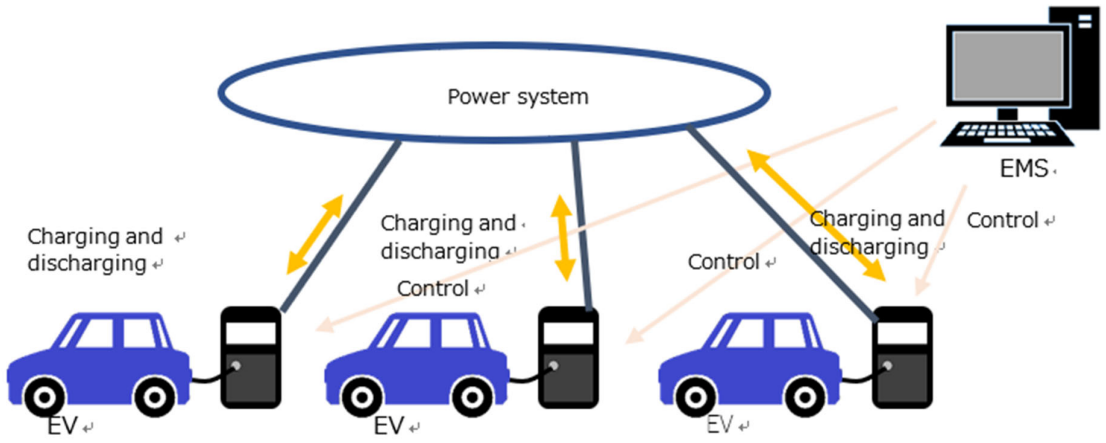


Figure: Charge-discharge control of EV on-board battery by V2G

Source: JICA consultants

5.4 Integrating V2G with DSM for Grid Stability

- A system that controls EV charging demand according to the supply and demand situation on the grid side (without discharging the batteries to the grid) is called V1G, and a system that can not only charge but also discharge electricity to the grid side is called V2G.
- It is expected to contribute to load levelling by utilizing EV on-board batteries as a resource for stabilizing power supply and demand, but in addition, batteries have very fast charging and discharging response rates, so if charging and discharging can be activated in real time according to instructions from the power system operator, it will be possible to absorb supply and demand fluctuations in shorter periods (in minutes to seconds), which will also contribute to stabilizing the system frequency.
- In this way, providing a service that contributes to stabilizing the system frequency to the system operator is called an ancillary service. It is also expected to contribute to enhancing the resilience of the power supply by utilizing EV on-board storage batteries as a power supply source during power outages.

5.4 Integrating V2G with DSM for Grid Stability

- Since the capacity of individual EV batteries is small, when dealing in these markets, it is common for operators called aggregators to bundle and control small-scale demand-side resources, including such batteries. Revenue generated through such market transactions is shared between the aggregator and the owner of the demand-side resource, in this case the EV owner.
- If EV owners are able to generate such revenue, it is expected to contribute to the promotion of EV adoption as it is deducted from the cost of EV purchase.

Presentation Material 2- 15

Activity 2-4-1 Benchmark on the Connection Guidelines of IRVE to the Distribution System Including Case Study in Japan Part (3)

Benchmark on the Connection Guidelines of IRVE to the Distribution System Including Case Study in Japan Part (3)

Activity 2-4-1

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-

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1.2 Technical Requirements & Measures for IRVE

2. Countermeasures for the Connection of IRVE
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2.2 Power Factor Control Countermeasures
2.3 Voltage Fluctuation Countermeasures
2.4 Charger Malfunction Countermeasures
2.5 Grid & Ground Faults Countermeasures
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2.9 High-Frequency Interference Countermeasure
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3.2 Voltage Fluctuation Mitigation Equipment
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3.6 Reverse Power Flow Mitigation Equipment
3.7 Grid Disturbance Synchronization Equipment
3.8 Grid Frequency Regulation Equipment
3.9 System Analysis (Phylogenetic Analyzer)

4. Substation Operation Control
4.1 Substation Anti-Islanding protection
4.2 Substation Reclosure Operation Scheme
4.3 Substation Power System Stabilizers
4.4 Substation Resistive Grounding System
4.5 Substation Power Communication

1. General Provisions

1.1 Scope of Application

- These countermeasures guidelines define the technical requirements for the connection of Electric Vehicle (EV) chargers and EV Fast Chargers with the electric power system operated by the utility.
- These technical requirements apply to all instances where EV chargers or EV fast chargers are installed and connected to the utility's grid within the service area.
- This encompasses private, commercial, and public charging infrastructure.
- For the purposes of this guidelines, any entity installing EV chargers or EV fast chargers is considered a customer (power-consuming facility).

1.1 Scope of Application

- **Governing Technical Connection of IRVE**
  - All technical conditions related to the connection of EV charging infrastructure shall comply with the following guidelines:
  - The Guidelines for Technical Requirements for Grid Interconnection to Ensure Electricity Quality.
  - The Company's Design Specifications for Grid Interconnection Facilities.
  - Any supplementary standards, regulations, or operational criteria as defined by the utility.
  - These measures ensure that the integration of EV chargers and EV fast chargers will not negatively impact grid stability, power quality, or safety.

1.2 Technical Requirements & Measures for IRVE

- The technical connection requirements for EV chargers and EV fast chargers **(Collectively Referred to as "EV Charging Equipment")** connected to the low-voltage distribution network.
- These technical measures are designed to ensure the quality, stability, and safety of the power system when integrating power electronic loads such as EV chargers.
- To maintain power quality and ensure system stability for all grid users, the customer shall, in agreement with the Company, install regulating and/or protective equipment if the load characteristics are found to negatively impact the grid, including but not limited to:
  - Significant load imbalance among phases
  - Voltage fluctuations or frequency instability
  - Harmonic distortion beyond acceptable thresholds
  - High-frequency interference
  - Any other phenomenon affecting grid quality

1.2 Technical Requirements & Measures for IRVE

■ Type of EV Charging Equipment

- All EV chargers and EV fast chargers employing power conversion technologies, including inverters, **AC/DC converters**, or rectifiers, shall be regarded as power electronic equipment.
- These chargers must comply with the technical connection specifications for power electronic devices to ensure compatibility and stability when integrated into the grid.

■ Electrical Configuration

- The internal electrical configuration of the EV charging equipment must match the voltage, frequency, and phase configuration of the low-voltage grid to which it is connected.
- This alignment ensures synchronization and stable operation of the charging equipment.

2. Countermeasures for the Connection of IRVE

2.1 Disconnection Points for EV Chargers

- EV chargers must be equipped with mechanical disconnect points to ensure safe and reliable disconnection from the grid. The disconnection configuration may include:
  - **Two mechanical Opening/Closing points**: Allowing for isolation of the charger from the grid.
  - **One mechanical Opening/Closing point, along with a gate block**: Specifically designed for disconnecting reverse power flow from the charger (e.g., reverse converters).
  - This ensures safe isolation of the charger during maintenance, fault conditions, or as required for disconnection.

2.2 Power Factor Control Countermeasures

- **EV Fast Chargers**: introduce reactive power into the grid, potentially affecting grid performance.
  - **At the point of connection:** They must be equipped with **Power Factor Correction (PFC)** systems to minimize reactive power, ensuring efficient energy draw and preventing inefficiencies in the grid.
  - The power factor shall be at least **85%** lagging relative to the grid voltage.
  - Leading (capacitive) power factor is prohibited to prevent voltage rise phenomena in the distribution network.
  - **Example**: A high-power DC fast charger can generate significant reactive power, especially during peak charging. PFC circuits bring the power factor closer to unity, improving energy efficiency, reducing **Harmonic Distortions**, and stabilizing the voltage across the grid.

2.3 Voltage Fluctuation Countermeasures

- **During Charging Operation:** The following measures must be implemented to control voltage fluctuations during charging operations:

  - If the operation of an EV fast charger leads to voltage deviations beyond the standard limits **(110 ± 6 V or 220 ± 20 V)** at neighboring low-voltage consumer terminals, the customer must implement automatic voltage regulation mechanisms (e.g., dynamic reactive power compensation or adaptive control).

  - In case of rapid load changes, such as during fast charging **Ramp-up/Down**, which could cause voltage flicker or transient disturbances, the charger must be equipped with voltage fluctuation suppression mechanisms. These may include ramp-rate control or load smoothing functions.

2.3 Voltage Fluctuation Countermeasures

- **Automatic Voltage Regulation:** (AVR) and Current-Limiting Reactors are used to manage voltage fluctuations and ensure the system remains stable.

  - **EV Fast Chargers**: Fast chargers need to handle voltage fluctuations effectively to maintain grid stability. They are typically equipped with voltage regulators to ensure operation within specified voltage ranges.

  - **Example**: In cases of voltage dips or spikes, fast chargers may disconnect until voltage returns to acceptable levels, similar to how a generator disconnects in response to unsafe voltage deviations.

  - Some DC fast chargers incorporate power conditioning equipment to adjust incoming voltage, ensuring a steady energy supply, much like a generator's **AVR**

2.3 Voltage Fluctuation Countermeasures

- **During Start-up or Disconnection:** If the EV fast charger uses a self-excited inverter or an equivalent topology, it must include an automatic synchronization function to align with the grid before drawing power.

  - If the charger causes a voltage drop of **10%** or more due to inrush current at start-up (particularly with chargers using large capacitor banks), countermeasures must be in place to limit or control such voltage dips.

  - If a voltage drop persists for an extended period, additional mitigation measures, such as soft-start systems or pre-charge circuits, must be implemented.

  - On circuits equipped with **Automatic Voltage Regulators** (AVRs), the disconnection of an EV fast charger must not cause downstream voltage deviations beyond acceptable limits. If this risk exists, voltage stabilization or automatic reactive power compensation must be incorporated into the system.

2.4 Charger Malfunction Countermeasures

- **Overvoltage and Undervoltage Protection:** To ensure the protection of the grid and surrounding users from failures originating from EV charging infrastructure, the following protective relays and functions must be installed

  - Overvoltage and undervoltage relays must be installed at the charger interface to automatically disconnect the equipment when abnormal voltage levels are detected.

  - Exception: If the EV charger is equipped with built-in protection functions that meet equivalent standards, this requirement may be waived, subject to utility approval.

2.5 Grid & Ground Faults Countermeasures

- **Short Circuit Protection:** Fast chargers are vulnerable to short-circuits and ground faults.
  - They must include protection mechanisms such as Ground Fault Circuit Interrupters **(GFCIs)**, overcurrent protection, and fuse links to isolate faults and prevent disruption to the grid.
  - **Example**: If a DC fast charger experiences a short-circuit, the system should immediately disconnect and trigger an alarm, similar to a generator's protective relays, which isolate faults to avoid wider grid issues.
  - **Ground-Fault Circuit Breaker:** A ground-fault circuit breaker with overcurrent protection shall be installed to protect against short-circuit faults and ground leakage currents at the interconnection point between the EV charger and the distribution network.

2.5 Grid & Ground Faults Countermeasures

- **Island Detection (High/Low Voltage Mixing) Protection**
  - A standalone operation detection system must be installed to detect islanding conditions or improper voltage mixing.
  - The system should immediately disconnect the EV charger to prevent back-feed or unstable operation.
  - An undervoltage relay capable of detecting voltage drops caused by upstream faults must be installed to ensure rapid disconnection of the EV charger.

2.6 Stand-Alone Operation Countermeasure

- **To prevent EV chargers or EV fast chargers from operating independently from the electric grid, the following grid and relays protection measures are required:**

  - **Stand-Alone Operation Detection Device**: A combination of passive and active detection systems must be integrated. These systems monitor the connection and operation of the EV charging infrastructure, ensuring it does not operate in isolation from the grid.
    - **Passive Systems**: Detect voltage imbalances or frequency deviations.
    - **Active Systems**: Enforce disconnection if such imbalances are detected.

  - These measures prevent the risk of islanding, where the EV charger continues operation during a grid failure, which could endanger both equipment and grid stability.

2.6 Stand-Alone Operation Countermeasure

  - Overvoltage/Undervoltage Protection: Prevents operation outside of the specified voltage range, protecting charger components.

  - Ground Fault Protection: Automatically disconnects the charger in case of a fault to ensure user safety.

  - Fault Isolation: When faults or system anomalies are detected, the charger disconnects from the grid, preventing potential issues such as harmonic distortion.

  - Frequency Relay System: A frequency increase relay and a frequency decrease relay must be installed to ensure that the charger disconnects in the event of frequency fluctuations outside of normal operational parameters, thus preventing islanding.

  - **Example**: The protection relays on fast chargers can be configured to detect grid disturbances, causing the charger to adjust or disconnect, much like how generators are protected from abnormal grid conditions.

2.7 DC Back-Flow Countermeasure

- **To prevent DC back-flow into the grid from the EV charger's DC side, the following measures must be implemented:**

  - **Isolation via Transformer**: A transformer (excluding single-winding transformers) must be installed between the charger's receiving point and its reverse converter to ensure no DC current flows back into the AC grid.

  - This is critical for systems that involve power electronics like inverters, which could otherwise generate unwanted DC components.

2.7 DC Back-Flow Countermeasure

  - **Exceptions**: The transformer requirement may be waived if
    - The DC circuit of the reverse converter is ungrounded or uses a high-frequency transformer.
    - A DC detector is installed on the AC output side of the converter, with an automatic cut-off function to disconnect the AC output if any DC current is detected.

  - These measures are essential to ensure the grid remains free from potentially damaging DC currents, which could affect other equipment and reduce overall power quality.

2.8 Power Quality Measures Countermeasure

- **Harmonics Suppression**
  - To maintain grid stability and ensure the power quality, the following guidelines are mandatory for minimizing harmonics generated by EV chargers:

  - **Total Current Distortion**:
  - For inverters used in EV chargers, the The total harmonic distortion (THD) on the current from the EV charger must not exceed **5%** of the rated current.

  - **Individual Harmonic Distortion**:
  - The current distortion factor for each individual harmonic order (e.g., 3rd, 5th, etc.) **Individual Order Distortion** must not exceed **3%** of the rated current.

  - These limits ensure that no single harmonic frequency will dominate, preventing severe distortion in the system.

2.9 High-Frequency Interference Countermeasure

- **High-Frequency Electromagnetic Interference** (EMI) and conducted interference can adversely affect the grid and nearby electrical systems. Therefore, the following measures must be implemented:

- **Electromagnetic Interference Mitigation**:
  - Appropriate shielding, filters, and other countermeasures must be implemented to prevent high-frequency EMI from emanating from the EV charger and affecting nearby devices.

- **Conducted Interference Prevention**:
  - Measures must be implemented to prevent interference from the charger's power electronics from traveling back onto the power lines, potentially disturbing other connected equipment.
  - These measures are crucial to ensure the EV charging system does not disrupt the electrical environment, safeguarding both the grid and sensitive electronic devices.

2.10 Transformer Step-Up Countermeasure

- **EV Fast Chargers**: Large-scale DC fast charging stations depend on transformers to step down high-voltage power to levels suitable for EV charging. These transformers must be protected from overcurrent and faults using relays and differential protection systems.

  - **Example**: If a transformer supplying fast chargers fails, the overcurrent relay disconnects the transformer and isolates the issue, similar to how generators protect transformers from fault conditions.

2.10 Transformer Step-Up Countermeasure

- In scenarios where voltage step-up is required between the generation facility and the distribution system, the transformer design shall meet the following criteria to ensure that EV chargers are supplied with stable and reliable power:

  - **Rated Voltage and Tap Settings:** The rated and tap voltages of the step-up transformer shall be defined based on the voltage conditions of the interconnected grid. These parameters ensure optimal matching between generator output and system operating voltage, which directly impacts the voltage levels that EV chargers receive.

  - **Rated Capacity:** The rated capacity of the step-up transformer shall align with the rated output power and power factor of the generator to ensure stable operation under full load conditions. Ensuring that step-up transformers meet these criteria is critical for maintaining sufficient power supply to EV chargers, especially during peak charging times when high power demand may occur.

2.10 Transformer Step-Up Countermeasure

- **Impedance Value:** Depending on the configuration of the interconnection system and the type of generation equipment employed, the impedance of the step-up transformer may be specified. This is required to:

  - Mitigate voltage drop,
  - Limit fault current during short-circuit conditions,
  - Ensure secure parallel operation with other grid-connected generation sources.
  - These steps help prevent fluctuations in voltage, which could affect the charging process of EVs. Proper impedance ensures that EV chargers, especially fast chargers, continue to receive reliable power during various grid conditions.

2.11 Automatic Load Limiting Countermeasure

- **Automatic Load Limiting**

  - In the context of EV fast chargers, automatic load limiting mechanisms at power generation facilities must ensure that the power distributed to the grid remains within safe operating limits, especially when a significant number of EV chargers are operating simultaneously.
  - These mechanisms should include coordination with charging stations, ensuring that power demand from the chargers does not cause grid instability or overloads, particularly during peak charging times.
  - If there are sudden surges in EV charging demand, especially during high-demand hours when many fast chargers are operating, power generation facilities should have control systems to curtail or increase power output. Overload relay protection (OLR) devices should be installed both at the generation site and within the EV charging infrastructure to detect and prevent overloads.

2.11 Automatic Load Limiting Countermeasure

- Moreover, the utility may intervene with remote controls to manage the output from EV chargers if system stability is threatened, such as during peak charging times or when faults occur in the grid.

2.12 System Frequency Abnormalities Countermeasure

- EV chargers should be equipped with smart charging capabilities to prevent abnormal frequency fluctuations, by working in coordination with the grid's frequency control mechanisms.

  - **Example**: fast chargers can adjust charging rates automatically to mitigate grid disturbances. This ensures the grid remains stable, particularly when large numbers of fast chargers are in operation.

3. Equipment for (Special High Voltage)

3.1 Power Factor Requirements Equipment

- **EV Fast Chargers**: Fast chargers can introduce reactive power into the grid, potentially affecting grid performance. They must be equipped with **Power Factor Correction (PFC)** systems to minimize reactive power, ensuring efficient energy draw and preventing inefficiencies in the grid.

  - To mitigate grid instability, EV chargers should dynamically adjust their power factor according to the time of day and grid conditions. For instance:
    - **Daytime**: Chargers should supply reactive power (leading power factor) to support grid voltage.
    - **Nighttime**: Chargers should maintain a unity power factor or absorb reactive power, depending on grid needs.

  - **Example**: A high-power DC fast charger can generate significant reactive power, especially during peak charging. PFC circuits bring the power factor closer to unity, improving energy efficiency, reducing **harmonic distortions**, and stabilizing the voltage across the grid.

3.2 Voltage Fluctuation Mitigation Equipment

- **EV Fast Chargers**: Fast chargers need to handle voltage fluctuations effectively to maintain grid stability. They are typically equipped with voltage regulators to ensure operation within specified voltage ranges.

  - **Example**: In cases of voltage dips or spikes, fast chargers may disconnect until voltage returns to acceptable levels, similar to how a generator disconnects in response to unsafe voltage deviations. Some DC fast chargers incorporate power conditioning equipment to adjust incoming voltage, ensuring a steady energy supply, much like a generator's Automatic Voltage Regulation (AVR).

3.3 Short-Circuit and Ground-Fault Current Equipment

- **EV Fast Chargers**: Fast chargers are vulnerable to short-circuits and ground faults.

- They must include protection mechanisms such as **Ground Fault Circuit Interrupters (GFCIs)**, **overcurrent protection**, and **fuse links** to isolate faults and prevent disruption to the grid.

  - **Example**: If a DC fast charger experiences a short-circuit, the system should immediately disconnect and trigger an alarm, similar to a generator's protective relays, which isolate faults to avoid wider grid issues.

3.4 Grid Protection and Relays Equipment

- **EV Fast Chargers**: Fast chargers require grid protection mechanisms similar to those used for generators, including:
  - **Overvoltage/Undervoltage Protection**: Prevents operation outside of the specified voltage range, protecting charger components.
  - **Ground Fault Protection**: Automatically disconnects the charger in case of a fault to ensure user safety.
  - **Fault Isolation**: When faults or system anomalies are detected, the charger disconnects from the grid, preventing potential issues such as harmonic distortion.
  - **Example**: The protection relays on fast chargers can be configured to detect grid disturbances, causing the charger to adjust or disconnect, much like how generators are protected from abnormal grid conditions.

3.5 Transformer Protection Equipment

- **EV Fast Chargers**: Large-scale DC fast charging stations depend on transformers to step down high-voltage power to levels suitable for EV charging.
  - **Rated Voltage and Tap Voltage**: For a 22 kV system, the rated voltage would match the secondary voltage, ensuring that the transformer steps up the voltage correctly for integration with the EV chargers.
  - **Impedance Voltage**: The transformer's impedance voltage must match the standard values for grid integration, ensuring that charging stations do not introduce excessive fault currents or destabilize the grid during short-circuit conditions.
- These transformers must be protected from overcurrent and faults using relays and differential protection systems.
  - **Example**: If a transformer supplying fast chargers fails, the overcurrent relay disconnects the transformer and isolates the issue, similar to how generators protect transformers from fault conditions.

3.6 Reverse Power Flow Mitigation Equipment

- **EV Fast Chargers**: In **Vehicle-to-Grid (V2G)** systems, where EVs supply power back to the grid, reverse power flow can cause voltage fluctuations. Fast chargers supporting V2G must regulate reverse power flow to avoid grid disturbances and maintain voltage stability.

  - **These steps help prevent fluctuations** into the grid, the fast charger must ensure that the power is synchronized with the grid's voltage, preventing instability, much like how generator systems manage reverse power flow to avoid voltage imbalances.

3.7 Grid Disturbance Synchronization Equipment

- **EV Fast Chargers**: Large-scale DC fast chargers at charging hubs must synchronize their charging loads with the grid's available capacity.

- In high-density charging stations, the chargers need to work together to avoid overloading the grid.

  - **Example**: When multiple fast chargers are connected to a single grid, their power consumption should be synchronized to prevent voltage fluctuations. Since these chargers use power converters, they must adhere to strict voltage tolerance and frequency compliance to ensure grid stability.

  - **Example**: During peak demand, fast chargers may adjust their charging rates to match the available power, minimizing their impact on the grid, similar to how generators synchronize their output with the grid to ensure overall stability.

3.8 Grid Frequency Regulation Equipment

- EV fast chargers increase their uptake and usage, especially during peak periods, grid frequency regulation becomes more important.
  - Fast chargers must be designed to adjust their charging output in response to frequency signals from the grid, contributing to frequency regulation and reducing the strain on the system.
  - **Example:** Fast Chargers must be capable of adjusting their output in real-time to match the system operator's **Automatic Frequency Control (AFC),** signals, ensuring that grid stability is maintained even when a large number of chargers are active.

3.8 Grid Frequency Regulation Equipment

- **Operable Frequency**
  - **Continuous Operation Frequency**: Chargers must operate within the frequency range of 48.5 Hz to 50.5 Hz, which is typical for grid-connected systems.
  - **Transient Operation Frequency**: During brief frequency fluctuations, EV chargers should remain functional between 47.5 Hz and 51.5 Hz.
  - **Protection Settings**: The frequency drop protection relay for EV chargers should be set to trip at 47.5 Hz, ensuring they disconnect from the grid to avoid overload or damage, and resume charging only when the grid stabilizes.

3.9 System Analysis (Phylogenetic Analyzer)

- **System Analysis (Phylogenetic Analyzer) Equipment**
- To ensure reliable performance and compliance with grid standards, the system's dynamic behavior should be continuously monitored. This is especially true for fast charging systems, which can experience varying loads that may influence grid stability.

- **System Monitoring Tools**: Advanced system analysis equipment, such as automatic oscilloscopes and harmonic monitoring devices, must be installed at key points to monitor the performance of both the generation system and EV fast chargers.

- **Data Logging**: The installation of event monitoring and logging equipment ensures that any disturbances or anomalies during charging periods can be accurately recorded and analyzed. This helps in fine-tuning the charging infrastructure to align with grid stability requirements.

4. Substation Operation Control

4.1 Substation Anti-Islanding protection

- **To prevent "Islanding"**

  - EV fast chargers must include **Anti-Islanding protection**. This means they must automatically shut off if they lose grid synchronization, ensuring that EV chargers are not left operating in isolation, which can harm grid stability and safety.

  - **Example**: For grid protection, **Substations Facilities** supplying power to EV fast chargers must ensure that appropriate disconnection points are established.

  - **Example**: for scenarios such as faults in the transmission line, grid infrastructure, or even within the charger facility itself, Fast chargers must have disconnection devices capable of isolating the charging points if the grid connection is compromised, ensuring protection both for the EVs and the grid infrastructure.

4.2 Substation Reclosure Operation Scheme

- **Substation Reclosure Operation Scheme**

  - Given that automatic reclosing systems are installed for transmission lines, coordination with fast chargers is essential. EV chargers must be designed to interact with these reclosing systems, ensuring that they will safely resume operation once the grid stabilizes after a transient fault, without causing additional strain on the grid or impacting other charging stations.

  - **Example**: for scenarios such as faults in the transmission line, grid infrastructure, or even within the charger facility itself, Fast chargers must have disconnection devices capable of isolating the charging points if the grid connection is compromised, ensuring protection both for the EVs and the grid infrastructure.

4.3 Substation Power System Stabilizers

- **Substations Performance Constants**

  - The substations supplying power to EV fast chargers must adhere to specific performance constants, ensuring stable supply even during high-demand charging periods. This is especially critical for fast chargers that can have fluctuating power demands depending on the number of vehicles being charged at a time.

- **Functions to Enhance Grid Stability**

  - For larger-scale EV fast charging networks, substations stations must incorporate grid stability controls like super-response excitation control, **Power System Stabilizers (PSS)**, and voltage regulation systems to adapt to the high demand imposed by the chargers.

4.4 Substation Resistive Grounding System

- **Resistive Grounding:**

  - For systems operating at 154 kV or below, a **Resistive Grounding System** is necessary to ensure that fast chargers are protected during faults while maintaining their connection to the grid

  - The integration of EV fast chargers into the grid requires consideration of the grounding system at the **Substation Transformer.**

  - A well-grounded transformer helps prevent electric shocks or malfunctions caused by faults, especially during instances where charging stations may experience electrical disturbances.

4.5 Substation Power Communication

- **Communication and Monitoring Functions:**
  - To ensure the reliability of the grid and protect the infrastructure of EV chargers, the following Power Supply Information Transmission Equipment should be implemented:
  - Transmitted telemetering equipment shall be installed to transmit essential system operation data to the MIS (Management Information System) must include:
    - Active power at the receiving point
    - Total energy delivered or received at the receiving point
  - These signals are necessary for real-time monitoring of the grid's operational status, ensuring that any fluctuations in supply or demand are promptly detected, which is crucial for managing power to EV charging stations, especially fast chargers that require consistent power availability for efficient operation.

4.5 Substation Power Communication

- For EV fast chargers, communication and monitoring systems must support bidirectional communication to ensure optimal performance and grid stability during high-demand periods.
  - **Reception Capabilities**: EV fast chargers should be capable of receiving direct power control (DPC) and automatic frequency control (AFC) command values from the grid operator, along with operation instructions to adjust charging rates in response to grid conditions. This allows the grid to manage load effectively during peak periods.
  - **Transmission Capabilities**: EV chargers should also transmit critical operational data, such as current power output, maximum potential output (for ultra-fast chargers), charging mode status (whether chargers are actively charging or on standby), and any fault conditions related to frequency regulation. This data transmission helps grid operators monitor charger status and ensure alignment with grid requirements.

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Activity 2-4-5 & 2-4-6 Review and Report the Comments on STEG' Guideline

Review and Report the Comments on STEG' Guideline

Activity 2-4-6

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-

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4.9_Annex

1. General Provisions

1.1_I. Object

Comment Type	Comments & Recommendations
Objective Definition	The current section would benefit from a clearer and more explicit statement of the guideline's purpose. It is recommended to emphasize that this document establishes comprehensive technical requirements for the connection and operation of IRVE (Infrastructures de Recharge de Véhicules Électriques) with the Tunisian national electricity grid. Including reference to IEC 61851-1 Scope will enhance international alignment and clarity. This clarity will help all stakeholders understand the scope and intent of the guideline from the outset. Kindly consider adding a brief rationale highlighting the importance of this guideline within Tunisia's energy transition framework.

1.2_II. Field Of Application

Comment Type	Comments & Recommendations
Scope Definition	The section should clearly define the range of IRVE installations covered, including all charging modes (Mode 1 to Mode 4), voltage levels, and types of sites (public, private, commercial). It is suggested to explicitly state any exclusions or special cases. Aligning the field of application with IEC 61851-1 will improve clarity and consistency for all stakeholders. A more comprehensive scope section helps users quickly understand the applicability of the guideline.

1.3_III. Definitions and Terminology

Comment Type	Comments & Recommendations
Clarity & Completeness	The terminology section currently omits several key definitions critical for understanding IRVE operation, It is recommended to enrich this section by incorporating definitions directly from IEC 61851-1 to ensure standardization and technical consistency. A glossary presented in a table format, cross-referenced with IEC clause numbers, will enhance usability and avoid misunderstandings among implementers and regulators. Kindly consider consulting IEC 61851-1 and IEC 62196 series for relevant terms.

1.4_IV. Normative References

Comment Type	Comments & Recommendations
Incompleteness	The current list of normative references is limited. We recommend including a comprehensive list of all relevant IEC standards, such as IEC 61851-1 (general requirements), IEC 61851-23 (DC EVSE requirements), IEC 62196 series (connectors), IEC 60364 (earthing and installation), IEC 61000 series (electromagnetic compatibility), and others. Including edition numbers and publication years will improve precision. Presenting these in a structured table with titles and applicability notes is suggested for clarity and ease of reference. This helps ensure the document is well grounded in international best practices.

1.5_V. Abbreviations

Comment Type	Comments & Recommendations
Missing Items	Important abbreviations such as, RCD (Residual Current Device), EVSE (Electric Vehicle Supply Equipment), PE (Protective Earth), and DSO (Distribution System Operator) are currently missing. Completing this section with all relevant abbreviations following IEC 61851-1 and IEC 60364-7-722 will improve reader comprehension and technical clarity. Kindly consider expanding this list to avoid ambiguity in subsequent articles.

2. Section A: Connection to the National Grid

2.1_VI. Introduction

Comment Type	Comments & Recommendations
General Clarity	The introduction would benefit from a clear statement outlining the purpose, regulatory context, and alignment with Tunisia's national energy strategy. It is recommended to mention the document's role in supporting safe, reliable, and efficient IRVE integration with the national grid, aligned with IEC 61851 and national policies. Such context helps users understand the rationale and scope, facilitating better compliance and stakeholder engagement.
Scope Anchoring	Please clarify how this guideline fits within the broader regulatory and technical framework, including relations with other standards and the role of STEG and DSOs. Providing a schematic or summary diagram may enhance comprehension.

2.2_VII. Charger Type

Comment Type	Comments & Recommendations
Terminology Consistency	The term "Charger Type" might lead to confusion. It is recommended to adopt the internationally recognized term "Charging Modes" (Modes 1 to 4) as defined in IEC 61851-1. This will harmonize terminology across documents and stakeholders.
Technical Specification	Kindly provide detailed examples of charging types covered under each mode, including AC single-phase, AC three-phase, and DC fast charging. Including typical voltage and current ranges for each mode and example use cases will make this section more informative and practical. Reference IEC 61851-1.

2.3_VIII. Technical Connection Requirements

■ Article 1: Connecting IRVE to the National Electricity Grid

Comment Type	Comments & Recommendations
Grid Interface	This section should specify clear technical parameters for connecting IRVE to the national grid. Recommendations include defining acceptable voltage levels, maximum current ratings, harmonic distortion limits, fault ride-through capabilities, and power quality requirements. Referencing IEC 61851-1 and IEC 61000-2-2/4 series will align this section with international standards and enhance grid stability considerations.
Coordination with STEG	It is important to define the responsibilities and coordination mechanisms among the customer, IRVE operator as STEG, and Distribution System Operator (DSO). Including pre-connection conditions, approval processes, and any necessary technical studies will facilitate smoother integration. Consider adding procedural flowcharts or checklists for practical guidance.
Documentation	Recommend explicit cross-referencing to IEC 61851 series and Tunisian grid regulations to ensure comprehensive technical and regulatory alignment.

2.3_VIII. Technical Connection Requirements

■ Article 2: General Characteristics of IRVE and Connection Works

Comment Type	Comments & Recommendations
Installation Certification	Recommend specifying that IRVE installation must be performed by professionals certified through approved training programs, ensuring competence and safety consistent with IEC 61851 and national regulations.
Equipment Compliance	Suggest clarifying that all charging stations, sockets, and cables must comply with the latest IEC 61851 series or equivalent, reinforcing uniform technical and safety standards.
High-Power Connections	Suggest including a provision that IRVE installations exceeding 44 kVA require private MV/LV substations at the customer's expense, aligning with grid protection and planning standards.
Power Quality Requirements	Recommend referencing specific IEC standards (IEC 61000 series) to manage harmonic currents, voltage fluctuations, and flicker, ensuring IRVE connection does not degrade network quality.

2.3_VIII. Technical Connection Requirements

■ Article 3: Connection Request

Comment Type	Comments & Recommendations
Procedure Clarification	The connection request process should be clearly described with all necessary documentation, technical data, and timelines for approval. It is recommended to align these procedures with IEC and EN 50110-1 best practices for electrical installations management. Clear communication channels and defined deadlines can improve customer experience and operational efficiency.

■ Article 4: Centralized Remote Control Operating Requirements

Comment Type	Comments & Recommendations
Interoperability	To promote interoperability and future-proofing, specify supported communication protocols such as ISO 15118 for vehicle-grid communication. Consider referencing IEC 61850 standards for communication within smart grids.
Control Hierarchy	It is recommended to clarify the roles of STEG and Tunisian authorities in the centralized remote control architecture between the Transmission System Operator (TSO), the Distribution System Operator (DSO), and IRVE operators. Aligning the control framework with IEC 61850 use cases will enhance coordination and operational security.

2.3_VIII. Technical Connection Requirements

■ Article 5: Protection System Requirements

Comment Type	Comments & Recommendations
System Integrity	This section should detail protective measures, including overcurrent protection, surge protection, residual current devices (RCDs), and disconnection times to ensure safety and system reliability. Alignment with IEC 60364 (specifically clause 722.54 for EVSE protection) and IEC 60364 is highly recommended.
Clarify Responsibilities	Kindly specify responsibilities for installation, maintenance, and periodic testing of protection systems between IRVE operators and STEG to avoid ambiguity and ensure accountability.

■ Article 6: Earthing Conditions

Comment Type	Comments & Recommendations
Technical Specificity	This section should elaborate on acceptable earthing system types, grounding resistance limits, and measurement methods, referencing IEC 60364. Including requirements for equipotential bonding and earthing conductor sizing would enhance technical rigor.
Safety Coordination	Recommend including coordination requirements for RCD types (A and B), rated residual operating currents, and sensitivity thresholds as per IEC 60364. Such specifications improve user safety and system reliability.

2.3_VIII. Technical Connection Requirements

■ Article 7: Metering System

Comment Type	Comments & Recommendations
Meter Type	It is advisable to specify minimum accuracy classes for metering equipment (e.g., Class 1.0 or 0.5S) and metrological certification requirements per IEC 62053-21 and IEC 62052-11 to ensure precise billing and regulatory compliance.
V2G Readiness	Consider addressing bidirectional (Vehicle-to-Grid) metering capabilities if applicable, especially for public and commercial IRVE installations, with references to IEC 62053-41. This would future-proof the system for emerging use cases.

■ Article 8: Technical Acceptance and Commissioning of IRVE

Comment Type	Comments & Recommendations
Test Protocols	We recommend including a comprehensive commissioning checklist, aligned with STEG regulations and based on IEC 61851-1, covering insulation resistance, earthing continuity, functional safety, and communication testing.
Witnessing	Clarify whether STEG representatives or authorized third parties are required for witnessing tests. Documenting acceptance criteria and reporting formats will facilitate consistent quality control.

2.3_VIII. Technical Connection Requirements

- **Article 9: Operating and Safety Instructions**

Comment Type	Comments & Recommendations
Clarity and User Guidance	It is recommended to provide clear, concise operating and safety instructions tailored for both technical personnel and end-users. Including step-by-step procedures for safe use, emergency shutdown, and troubleshooting will enhance user safety and reduce operational errors. Reference to IEC 61851 on safety instructions can strengthen this section. Consider including pictograms or illustrated guides for broader accessibility.
Training and Awareness	Suggest emphasizing the importance of user and operator training programs to ensure proper understanding of safety protocols, and periodic refresher training to maintain high safety standards. This will support sustained compliance and reduce risks.

2.3_VIII. Technical Connection Requirements

- **Article 10: Operating Conditions for Public and Private Group Customers**

Comment Type	Comments & Recommendations
Differentiation & Specificity	It would be helpful to clearly distinguish operating conditions specific to public users (e.g., general public charging stations) versus private group customers (e.g., corporate or residential complexes). Tailoring operational parameters such as access control, peak usage management, and service levels will improve applicability. Consider referencing IEC 61851-1 clauses on access and charging control.
Reliability and Availability	We recommend defining minimum service reliability levels and maintenance responsibilities for each customer group to ensure consistent performance and customer satisfaction. Including contingency plans for outages and faults can add robustness.

2.3_VIII. Technical Connection Requirements

- **Article 11: Compliance with Technical Connection and Operating Requirements for Public and Private Collective Customers**

Comment Type	Comments & Recommendations
Compliance Verification	Suggest clarifying compliance verification procedures, and documentation requirements for public and private collective customers. This promotes transparency and accountability. Reference to IEC 61851
Reporting & Penalties	Recommend including guidelines on reporting non-compliance and corrective actions, along with the consequences of failure to meet technical and operational requirements. Clear, documented enforcement processes will strengthen guideline implementation.

3. Section B: Communication & Steering

3.1_IRVE Management

Article 12: Parties Involved in IRVE Management

Comment Type	Comments & Recommendations
Stakeholder Roles	This section would benefit from a detailed mapping of all parties involved in IRVE management, including the STEG, and Customer (IRVE owner or operator), facility owners, maintenance contractors, and end-users. Clarifying roles, responsibilities, and communication protocols will reduce conflicts and streamline operations. Reference to IEC 61850 and IEC 61851-1 for stakeholder coordination is suggested.
Governance Framework	Consider recommending establishment of a governance framework or coordination committee to facilitate regular communication and decision-making among parties. This enhances operational efficiency and responsiveness.

Article 13: Interaction between the Parties Involved

Comment Type	Comments & Recommendations
Communication Protocols	Recommend defining standardized communication protocols and interfaces between involved parties to ensure seamless data exchange and operational coordination. Reference to OCPP (Open Charge Point Protocol) and IEC 61850 standards will ensure interoperability and future-proofing.
Conflict Resolution	Including a conflict resolution mechanism or escalation path can help address operational disputes swiftly and fairly, enhancing stakeholder confidence.

3.1_IRVE Management

Article 14: Supervision and Energy Control Platform for Public use

Comment Type	Comments & Recommendations
Platform Requirements	Suggest elaborating technical requirements for the energy supervision and control platform, such as real-time monitoring capabilities, user access levels, and integration with smart grid management systems. This section should align with IEC 61850 and EV integration.
Data Analytics & Reporting	Recommend including provisions for data analytics, reporting tools, and dashboards to support operational optimization and regulatory compliance. This will add value to system operators and public users alike.

Article 15: Energy Management of Recharging

Comment Type	Comments & Recommendations
Load Management	Including detailed strategies for energy and load management, such as demand response, load shedding, and peak shaving, will improve grid stability and cost efficiency. Reference IEC 61851 on energy management is advisable.

3.1_IRVE Management

Article 16: Data Transfer Time

Comment Type	Comments & Recommendations
Latency Requirements	It is beneficial to specify acceptable data transfer latencies for different types of communications (e.g., control commands, metering data) to ensure timely system responses. Reference to IEC 61850 and related communications standards can support this.

Article 17: Transfer of EV Charging Data for Public Use

Comment Type	Comments & Recommendations
Data Standards	To promote interoperability and compliance, suggest specifying data formats and communication protocols for EV charging data transfer, such as those defined in OCPP and IEC 61850. Clear data standards facilitate integration and data exchange across platforms.
Privacy & Confidentiality	It is important to highlight data privacy considerations and compliance with relevant data protection laws, ensuring personal and usage data confidentiality for public users.

3.1_IRVE Management

Article 18: Communication Security

Comment Type	Comments & Recommendations
Cybersecurity Framework	Recommend including cyber-security requirements such as authentication, encryption, and intrusion detection consistent with IEC 61850-90-8 standards, supporting secure demand-response interactions. This will mitigate cyber risks in IRVE communications.
Access Control	Specify access control mechanisms and secure credential management to protect IRVE infrastructure and data from unauthorized access.

Article 19: Information Security

Comment Type	Comments & Recommendations
Data Integrity & Confidentiality	Suggest expanding on information security policies to include data integrity, confidentiality, and availability, aligned with best practices from IEC 27001 and GDPR (General Data Protection Regulation) ,principles where applicable.
Incident Response	Including procedures for incident detection, reporting, and response will strengthen resilience against information security threats and help ensure rapid recovery.

3.2_General Notes

Topic	Recommendation
Document Consistency	Kindly ensure consistent use of terminology, units, and formatting throughout the document to enhance professionalism and readability.
References to Standards	Repeatedly cross-check and explicitly cite relevant IEC standards to strengthen the document's technical credibility and ease of future updates.
Stakeholder Inclusion	Consider adding a stakeholder engagement plan section to define roles and responsibilities clearly among regulators, STEG, IRVE operators, and end-users.
Annexes	Suggest including annexes with sample forms, templates, test protocols, and a glossary to support practical implementation.

4. Summary Report for STEG: Accomplishments and Achievements of the Guidelines

4.1_Structure Overview

Section	Title	Subsections / Objectives and Notes
A	General Provisions	Scope, Purpose, Legal Basis, Terminology, and Document References
B	Charging Modes	Technical and compliance specifications for Modes 1 to 4 as per IEC 61851
C	Electrical Connection Requirements	Specifications for electrical interconnection to STEG's LV and MV distribution networks
D	Metering and Communication Standards	Technical metering, communication, and data transmission requirements
E	Installation, Safety, and Environmental Conditions	Installation norms, protection measures, site conditions, and ambient environment constraints
F	Compliance Procedures and Documentation	Steps for project compliance verification, technical audits, and approval cycles
G	Annexes	Supplementary diagrams, example schemas, list of references, and acronym index

4.2_Section A: General Provisions

Section	Section Title	Subsections / Objectives and Notes
1	Purpose	Defines the intent of the document and strategic objectives for IRVE integration
2	Scope of Application	Specifies boundaries and applicable infrastructure types and scenarios
3	Diagram Concept	Provides schematic overview of system architecture and component interaction
4	Definitions and Terminology	Contains detailed definitions, key terms, abbreviations, and full forms for clarity and shared understanding
5	Normative References	Lists key international and national standards (e.g., IEC), critical product-related documents, usage guidance, and legal disclaimers
6	Field of Application	Further technical granularity on where and how the guideline applies
7	Complementary Documentation	Related documents necessary for compliance and operational understanding

4.3_Section B:Charging Modes and Technical Specifications

Section	Section Title	Subsections / Objectives and Notes
1	Mode 1 Charging: Standard Socket-Based Charging	Overview of system functionality, electrical interface, installation/environment, safety protections, communication, compliance, and regulations.
2	Mode 2 Charging: Portable Equipment-Based Charging	Covers system overview, power architecture, installation and environmental needs, safety measures (including standards and compliance), communication, and regulatory notes.
3	Mode 3 Charging: Dedicated AC Charging using a Specific IRVE	Describes system scope, power interface, installation requirements, safety protections (including environmental standards), interoperability, performance criteria, and regulations.
4	Mode 4 Charging: DC Fast Charging using Electrical Separation	Detailed sections on functional scope, power classification, supply considerations; electrical interface; comprehensive safety and protection measures; communication interfaces; energy metering, data logging, billing; meter accuracy; full compliance, certification, and documentation requirements; includes a disclaimer section.

4.4_Section C: Technical Requirements for IRVE Connection to the National Grid

Section	Section Title	Subsections / Objectives and Notes
1	Introduction and General Provisions	Objectives, legal and regulatory context, reference standards, terminology, scope, general functional and electrical compatibility requirements, and overview of IRVE connection to the national grid.
2	Power and Voltage Specifications, Power Quality Characteristics, and Connection Works	General requirements, EMC, disturbance impacts (wave quality, DC components, harmonics, flicker, voltage unbalance), with tables and figures detailing standards and measurements.
3	Plugs, Socket-Outlets, Vehicle Connectors and Vehicle Inlets	Scope, installation and personnel requirements, circuit and environmental specs, exclusions, interface definitions with diagrams.
4	Dimensional Compatibility and Interchangeability Requirements	AC pin and contact-tube accessories, DC configurations, contact sequencing, combined interfaces, general requirements, operating voltage and frequency ranges, compatibility tables.
5	Immunity Against Disturbances	Low Voltage Ride Through (LVRT) capability, voltage evaluation, post-fault recovery, system stability requirements including frequency and voltage stability, reactive power control modes, with graphical representations and tables.
6	Electrical Safety Requirements and Electrical Protection	Protection objectives, electrical separation, shock protection measures with summary tables, fault detection/disconnection, protection coordination, applicable standards summary.
7	Safety Operation Communication Protocols and Interoperability Acceptance	EMC requirements for onboard and off-board equipment, grid integration and communication integrity, interoperability standards, data security/privacy, certification, compliance testing, and signal filtering device specifications.

4.4_Section C: Technical Requirements for IRVE Connection to the National Grid

8	Technical Requirements for Metering, System Monitoring, and Energy Management	Metering accuracy and standards, communication, smart grid integration, demand response, load management, data privacy/security, certification and maintenance, including monitoring and remote control systems for private/public stations, with standards tables.
9	Technical Compliance, Certification, and Documentation Procedures	Compliance scope, technical conformity, certification types (type, installation, maintenance), documentation, commissioning processes for private/public infrastructure, connection and operating compliance, with disclaimers.
10	Grid Connection and Application Procedures	Connection schemes with schematic diagrams for LV and MV networks, connection request procedures, compliance with requirements, and disclaimers.

4.5_Section D: Technical Requirements for EV Fast-Charging Systems

Section	Section Title	Subsections / Objectives and Notes
1	Standards and Technical Framework	Defines the conductive charging system framework, DC fast-charging station requirements, classification of charging modes, communication protocols, and mandatory functions with reference to IEC standards and key classification tables.
2	Technical Requirements for Fast-Charging EVSE Installations	Details classification, power cable specifications (thermal management included), plug and connector types, connection methods, and compliance criteria for EVSE hardware in fast-charging installations.
3	Electrical Architecture for Fast-Charging Systems	Covers electrical design principles, installation and switchgear requirements, transformer specifications, protection and safety measures, metering and monitoring protocols, installation procedures, and commissioning guidelines supported by system diagrams.
4	Performance, Safety, and Protection Requirements	Specifies safety verification, fault detection, surge and overvoltage protection, earth leakage safeguards, power quality compliance, and applicable IEC standards for operational reliability and safety of fast-charging systems.
5	Communication and Interoperability Requirements for EV Fast-Charging Systems	Defines communication standards, data exchange during charging, monitoring, fault handling, interoperability with diverse EV models, regulatory compliance, and disclaimers to ensure system compatibility and security.

4.6_Section E: Communication and Telecommunication Requirements for EV Fast-Charging Systems

Section	Section Title	Subsections / Objectives and Notes
1	General Framework	Overview of communication and telecommunication requirements for EV fast-charging systems.
2	Stakeholders and Interactions in IRVE Management	Identification of key stakeholders and their roles in communication and management of IRVE systems.
3	Requirement Supervision Platform and Energy Management for Public IRVE	Comparison of IEC 61851-24 and ISO 15118 protocols, scope and functions of each, with a summary table of differences.
4	Communication and Protocol Infrastructure	Communication architecture, interoperability, layered protocols, safety and security measures, data management, connector standards, and STEG compliance.
5	Telecommunication System Architecture and Management	System design and customization, interoperability, data exchange, smart charging applications, security, compliance, and applicability notes for private and public installations.

4.7_Section F: Protection and Safety Requirements

Section	Section Title	Subsections / Objectives and Notes
1	Protection System Requirements	Scope, general obligations, electric shock protection (direct/indirect contact, TN disconnection times), documentation, LV installations compliance, integration with STEG network.
2	Protection Against Voltage Disturbances and Electromagnetic Interference	Scope, overvoltage and electromagnetic disturbance protection, Insulation Fault Location System (IFLS) requirements and scope.
3	Cable Insulation, Shielding, and Electromagnetic Compatibility Measures	Scope and detailed requirements for cable insulation, shielding, and EMC measures.
4	Safety and Fault Detection	Procedures for disconnection and emergency shutdown, circuit and overload protection, residual current protection, overcurrent protection, lightning protection (LPLs, risk management, PECS safety), and monitoring/protective devices. Includes related tables for disconnect times and lightning parameters.
5	Environmental and Physical Protection	General requirements for earthing and grounding (protective conductor, equipotential bonding, design), enclosure protection standards (IP/IK codes), regulatory applicability, and protection against mechanical impacts.

4.8_Section G: IRVE Equipment's Installation Requirements and Tests

Section	Section Title	Subsections / Objectives and Notes
1	Scope	Defines the application boundaries and general intent for IRVE equipment installation and testing requirements.
2	Equipment Installation	General installation requirements and specific guidelines for charging stations.
3	Technical Provisions for IRVE Components	Detailed technical requirements for charging stations, charging points, and charging cables.
4	Identification and Environmental Protection	Requirements for connection point identification, ingress protection (IP), and additional safety measures for fast chargers at fuel stations. Includes multiple tables and figures on flammable vapour retention areas, hazardous exclusion zones, and monitoring requirements for refuelling station installations.

4.9_Annex

Section	Section Title	Subsections / Objectives and Notes
Annex A	Applicable Standards for IRVE Components	Lists relevant standards governing components used in IRVE systems.
Annex B	Technical Standards and Requirements Table	Provides a table detailing minimum technical, safety, performance, and environmental requirements for key IRVE components in public systems.
Annex C	Environmental and Service Conditions for Outdoor IRVE Installations	Specifies standard environmental and service conditions across different Tunisian regions, supported by a detailed table.
Annex D	Responsibilities of Owner	Defines the duties and obligations of IRVE system owners.
Annex E	Final Verification Checklist	Checklist for final verification of fast-charging EVSE installations to ensure compliance.
Annex F	Single-Line Diagram Symbols	Provides standard symbols used in single-line diagrams for IRVE installations and documentation.

Appendix 2- 1

Questionnaire to Support IRVE Electric Mobility Transition

Questionnaire to Support IRVE Electric Mobility Transition

JICA Expert Team

February 2025



Contents

1. Section 1: Respondent Demographics.
2. Section 2: Respondent Information.
3. Section 3: Respondent's Place of Residence.
4. Section 4: Respondent Vehicle Ownership.
5. Section 5: Respondent Driving Habits.
6. Section 6: Respondent Charging Habits.
7. Section 7: Respondent of EV Charging Habits.
8. Section 8: Awareness and Concerns of Respondent.
9. Section 9: Respondent Future Considerations.

Introduction

- This Questionnaire presents a comprehensive survey conducted to understand the current state of electric vehicle (EV) adoption in Tunisia.
- The study highlights key insights into demographics, vehicle ownership, driving habits, infrastructure availability, and public perceptions.
- The goal is to analyse emerging trends, forecast EV penetration, and estimate the electricity demand for EV chargers to inform future planning.
- Additionally, to assess the impact of EVs on the grid, supporting widespread adoption across the country and contributing to global sustainability objectives.

Section 1: Respondent Demographics

Section 1: Respondent Demographics

- This section covers respondent demographics, including region, housing type, and vehicle ownership, to assess the potential for EV adoption across different areas.

Table: Population Distribution by Region

What is the number of Population?		
Region	**Number**	**Percentage**
All Tunis		
Tunis		
Sfax		
Sousse		
Gabès		
Kairouan		
Gafsa		
Bizerte		
Ezzahra		
Ariana		
Medenine		

Section 1: Respondent Demographics

- This section covers respondent demographics, including region, housing type, and vehicle ownership, to assess the potential for EV adoption across different areas.

Table: Housing for General Population in Tunis

Housing for the general population in Tunis?			
Percentage of dwellings	**Single-dwelling buildings**	**Two-dwelling buildings**	**Three or more dwelling buildings**
Conventional passenger vehicle stock by dwelling type in 2024			
Electric passenger vehicle stock by dwelling type in 2024			
Electric passenger vehicle stock by dwelling type in 2030			

Section 1: Respondent Demographics

- This section covers respondent demographics, including region, housing type, and vehicle ownership, to assess the potential for EV adoption across different areas.

Table: Number of EV and Conventional Cars

What is the number of EV and conventional cars?						
Region	No EV	Percentage	Expected 2030	No Fuel	Percentage	Expected 2030
All Tunis						
Sfax						
Sousse						
Gabès						
Kairouan						
Gafsa						
Bizerte						
Ezzahra						
Ariana						
Medenine						

Section 1: Respondent Demographics

- This section covers respondent demographics, including region, housing type, and vehicle ownership, to assess the potential for EV adoption across different areas.

Table: Number of IRVE and Gas Stations

What is the number of Existing charging infrastructure and Gas stations?						
Region	No Gas Stations	Percentage	No IRVE	Percentage	Expected IRVE 2030	Percentage
Tunis						
Sfax						
Sousse						
Gabès						
Kairouan						
Gafsa						
Bizerte						
Ezzahra						
Ariana						
Medenine						

Section 2: Respondent Information

Section 2: Respondent Information

- This section provides insights into the respondents' demographic characteristics, such as gender, age, occupation, and household income.

Table: Gender

What is your Gender?			
Gender	**Answer**	**No**	**Percentage**
Male			
Female			

Table: Age

What is your age range?			
Age group	**Answer**	**No**	**Percentage**
Under 35			
35-49 years			
50-64 years			
65+			

Section 2: Respondent Information

- This section provides insights into the respondents' demographic characteristics, such as gender, age, occupation, and household income.

Table: Occupation

What is your occupation?			
Type of Occupations	**Answer**	**No**	**Percentage**
Private sector employee			
Public sector employee			
Self-employed			
Student			
Unemployed			

Section 2: Respondent Information

- This section provides insights into the respondents' demographic characteristics, such as gender, age, occupation, and household income.

Table: Household Income

Household Income TND			
Income TND	**Answer**	**No**	**Percentage**
Less than 500			
500 - $1000			
1000 - 2000			
2000 – 3000			
Rather not say			

Section 3: Respondent's Place of Residence

Section 3: Respondent's Place of Residence

Table: Place of Residence

What is you place of residence?			
Area	**Answer**	**No**	**Percentage**
Suburban area			
Urban area, e.g. city center			
Semi - rural area			
Rural area			

Section 4: Respondent Vehicle Ownership

Section 4: Respondent Vehicle Ownership

Table: Own an EV

Do you currently own an electric vehicle (EV)?			
Own (EV)	**Answer**	**No**	**Percentage**
Yes			
No			

Table: Considering Purchasing an EV

Are you considering purchasing an EV in the future Or No?			
Answer	**Answer**	**No**	**Percentage**
Yes, within One year			
Yes, within 3 years			
Yes, within 5 years			
No			

Section 4: Respondent Vehicle Ownership

Table: Type of Vehicle

What type of vehicle do you currently own?			
Type of vehicle	**Answer**	**No**	**Percentage**
Gasoline-powered			
Diesel-powered			
Hybrid			
EV			
None			

Section 5: Respondent Driving Habits

Section 5: Respondent Driving Habits

Table: Kilometers on a Typical Day

How many kilometers would you drive your vehicle on a typical day?			
Distance in Km	**Answer**	**No**	**Percentage**
0-10 km			
11-25 km			
26-50 km			
51 km +			

Table: Drive on a Trip Exceeds Range

How often do you drive on a trip that exceeds the range?			
Trip exceeds the range	**Answer**	**No**	**Percentage**
A few times or more a month			
Every few months			
Less often			

Section 5: Respondent Driving Habits

Table: Certain Types of Trips

Are there certain types of trips that you would not use your EV for?			
Certain types of trips	**Answer**	**No**	**Percentage**
Yes			
No			

Section 6: Respondent Charging Habits

Section 6: Respondent Charging Habits

Table: Typical Time of Charge

If you own an EV what is the typical time of day you prefer charge?			
Typical time for charging	Answer	No	Percentage
Morning (6 AM-12 PM)			
Afternoon (12 PM-6 PM)			
Evening (6 PM-12 AM)			
Night (12 AM-6 AM)			

Section 6: Respondent Charging Habits

Table: Favourite Charging Place

What is your favorite charging place you charge if you own an EV?			
Charging place	**Answer**	**No**	**Percentage**
Home			
Work			
In a public parking lot			
At a supermarket / mall			
At a petrol station			
On-street/ roadside			
In a private parking lot			
At a public library/ cafe / restaurant			
Other			

Section 6: Respondent Charging Habits

Table: Refrain from using Public Chargers

Which of the following, if any, stops you from using public chargers more often? Please select all that apply			
Activities hinder people from using public EV chargers	**Answer**	**No**	**Percentage**
Eat / drink			
Go shopping			
Go for a walk			
Use a public facility/library / leisure			

Table: Long Typically to Charge

If you are using a public charger, how long would you typically want to charge for?			
Time of Charging	**Answer**	**No**	**Percentage**
Less than 10 minutes			
10-19 min			
20-39 min			
40-59 min			
1 hour or longer			
Don't know / can't say			

Section 7: Respondent of EV Charging Habits

Section 7: Respondent of EV Charging Habits

Table: Type of Charger(s) at Home

What type of charger(s) do you have at home? Please select all that apply			
Type of charger(s)	**Answer**	**No**	**Percentage**
Slow (Level 1)			
Fast (Level 2)			

Table: level of the Battery Capacity Gets Down

What level do you typically let the battery capacity get down to before you charge it?			
Battery capacity	**Answer**	**No**	**Percentage**
75% or higher			
50-74%			
25%-49%			
10-24%			
Less than 10%			
Don't know			

Section 7: Respondent of EV Charging Habits

Table: Preferred Charging Locations

Where are your preferred charging locations?			
Charging Place	**Answer**	**No**	**Percentage**
Home			
Work			
Public parking lot			
Supermarket/mall			
Petrol station			
On-street/roadside			
Private parking lot			

Table: Types of Trips

If using a PUBLIC charger, which would you be more likely to do?			
Public charging preferences	**Answer**	**No**	**Percentage**
Plan and know in advance which public charge stations I will use			
Charge spontaneously and locate public charging stations on route			

Section 7: Respondent of EV Charging Habits

Table: Types of Trips

On what types of trips do you typically use public chargers? Please select all that apply			
Types of trips	**Answer**	**No**	**Percentage**
Long weekends/holiday trips			
Day trips during leisure time			
Short trips around town			
Commuting / regular daily weekday travel			
Other			
None of these			

Section 7: Respondent of EV Charging Habits

Table: Refrain from using Public Chargers

Which of the following, if any, stops you from using public chargers more often? Please select all that apply			
Barriers to public charging	**Answer**	**No**	**Percentage**
Having to queue / wait for a charger			
Cost to charge			
Nothing stops me from using a public charger more			
They aren't located in convenient places			
Concern about degrading battery through a fast-charging network			
It takes too long to charge			
I don't always know where to find them			
They're not compatible with my electric vehicle			
They're all too far away from me			

Section 8: Awareness and Concerns of Respondent

Section 8: Awareness and Concerns of Respondent

Table: Impact EVs on the Electric Grid

Are you aware of the impact EVs can have on the electric grid?			
EVs impact on the electric grid	**Answer**	**No**	**Percentage**
Yes			
No			

Table: Current Power IRVE Infrastructure in Tunisia

Do you think the current power infrastructure in Tunisia can support widespread EV adoption?			
EVs impact on the electric grid	**Answer**	**No**	**Percentage**
Yes			
No			
Unsure			

Section 8: Awareness and Concerns of Respondent

Table: Challenges Tunisia Faces in Supporting EV Adoption

What challenges do you think Tunisia faces in supporting EV adoption?			
challenges of EV adoption	**Answer**	**No**	**Percentage**
Lack of charging infrastructure			
High electricity costs			
Insufficient power grid capacity			
Lack of government incentives			
Others (please specify):			

Section 9: Respondent Future Considerations

Section 9: Respondent Future Considerations

Table: Encourage to Adopt an EV

What would encourage you to adopt an EV?			
Encourage of EV adoption	Answer	No	Percentage
Lower EV prices			
More charging stations			
Incentives or subsidies			
Environmental concerns			

Source: Electric Vehicle Charging Survey, Insights into EV owners' charging habits, and use of public EV charging, Nicola B. et al. 2021.
Source: Regional Charging Infrastructure Requirements in Germany Through 2030, Michael Nicholas, Sandra Wappelhorst, ICCT, 2020.
Source: JICA Research Team

A Comprehensive Survey Report

- Conclusion
- Fostering the adoption of electric vehicles in Tunisia requires a multifaceted approach that addresses regional disparities in vehicle ownership, infrastructure availability, and consumer perceptions.

Appendix 2- 2

STEG Methodology for Forecasting Electricity Demand: EV Penetration Scenarios in Tunis

STEG Methodology for Forecasting Electricity Demand: EV Penetration Scenarios in Tunis

Development of a Questionnaire for a Survey for a Benchmark on the Data Collection Method for Modeling Car Use."

Activities (2-3-4 & 2-3-5)

Introduction

The activities 2-3-4 and activity 2-3-5 of "the project for low carbon and stable supply at power system in Tunisia" is to propose electricity demand forecast based on a scenario of EV penetration.

As part of this activity, discussions focused on the electricity demand forecasting methodology and the simulation of electric vehicle charging load. During these discussions, WG2 highlighted the lack of mobility data. This data is necessary to estimate future electricity demand from electric vehicles.

During the third JICA expert mission, a questionnaire was proposed to support the IRVE transition to electric mobility. This proposal of JICA experts is presented in this document. The second section of this document contains a detailed request and proposal about mobility data collection from WG2.

The purpose of this questionnaire is to collect data that can be used for both Macro-level demand forecasting, based on statistical trends, and Micro-level analysis of charging behavior and travel patterns around urban centers.

1. Questionnaire to Support Electric Mobility Transition

Introduction

This Questionnaire presents a comprehensive survey conducted to understand the current state of electric vehicle (EV) adoption in Tunisia. The study highlights key insights into demographics, vehicle ownership, driving habits, infrastructure availability, and public perceptions. The goal is to analyse emerging trends, forecast EV penetration, and estimate the electricity demand for EV chargers to inform future planning.

Additionally, to assess the impact of EVs on the grid, supporting widespread adoption across the country and contributing to global sustainability objectives.

Electric Vehicle Adoption in Tunisia:

A Comprehensive Methodology and Framework

Survey Report

2. Detailed Requests and Proposals

2.1. Passenger Mobility Data Collection Plan

2.1.1. Objectives

In line with a transition to electric mobility, electricity demand scenarios should be studied using an energy demand analysis model to assess the impact of this mobility transition on energy demand. The case studies on energy demand forecasting presented by WG2 during the third mission were carried out on the basis of several assumptions concerning the transport sector. As mentioned in the introduction, the lack of mobility data can distort the assumptions developed for the construction of energy demand scenarios.

The request of WG2 is to collaborate on passenger mobility data collection solutions, so that we can:

2.1.2. Framework of Passenger Mobility Data Collection

1) Key Stakeholders

- Ministry of Transport
- Institut National de la Statistique (INS)
- Société des Transports de Tunis (Transtu)
- Municipalities & Governorates
- Louage/Taxi Unions
- Tunisian Railways (SNCFT)
- Universities (e.g., ENIT, Sup'Com)

Suggestions : Framework of Passenger Mobility Data Collection

- Clarify roles: The list is complete, but it would be clearer to specify each stakeholder's expected contribution (e.g., data provider, analyst, field collaborator).
- Ministry of Transport: National policy alignment and coordination
- INS: Lead in household survey design and data handling
- Société des Transports de Tunis Transtu: Provide operational transport data
- Municipalities & Governorates: Local facilitation and pilot site selection

- Louage/Taxi Unions: Cooperation for on-the-ground interviews and tracking
- Universities (ENIT, Sup'Com): Methodological support and student involvement
- Tunisie Télécom, Ooredoo, and Orange Tunisie: Provide anonymized mobility datasets

2) Data Collection Components

A. Household Travel Survey (Pilot in Greater Tunis, then expand)

- Partner with INS and local universities
- Collect trip-level data (origin, destination, purpose, mode, duration)
- Use tablets for digital data entry

Sample size: ~2,000–5,000 households
Tools: KoboToolbox, SurveyCTO, OpenDataKit (ODK)

Suggestions: Data Collection Components as (pilot project)

- Clarify phased rollout: Suggest adding a timeline or strategy for scaling from pilot project to national level.
- Justify sample size: It's helpful to briefly explain why 2,000–5,000 households is adequate for Tunis pilot project and the next expected sample for national level.
- Add this sentence: The sample size will ensure statistically valid representation across socioeconomic groups and urban zones in Greater Tunis and will inform subsequent national rollout.

B. Mobile Phone Data (via Telecom Providers)

- Collaborate with **Tunisie Télécom**, **Ooredoo**, and **Orange Tunisie**
- Use anonymized Call Detail Records (CDRs) and triangulation to infer movements between areas

Use: Intercity flows, peak travel times, commuting patterns

Suggestions: Mobile Phone Data (via Telecom Providers)

- Add a line about using aggregated, anonymized movement matrices to reassure about privacy

C. Public Transport Data

- Request:
  - Passengers number data from **Transtu** (Metro, Bus in Tunis)
  - Timetables and boarding data from **SNCFT**
- Place GPS trackers on sample routes (louage, buses)

Use: Service coverage, usage intensity, delays

Suggestions: Public Transport Data

- Add a line about addressing data availability risk: Acknowledge possible data quality or availability issues and propose mitigation (e.g., sampling or estimation).

D. Ride-Hailing and App Data

- Request anonymized trip data from **Bolt**, **Intigo**, **…**
- Partner with Google Mobility for historical trends

Use: Urban travel behavior, price sensitivity, peak time analysis

JICA_WG2_Suggestions: Ride-Hailing and App Data

- Specify access mechanism: Will data sharing be done through partnership agreements, NDAs, or open APIs?

A. Louage & Taxi Data

- Conduct structured interviews and GPS tracking with louage drivers
- Map routes, waiting times, and passenger volumes
- Survey passengers at major hubs like Bab Alioua (Tunis), Sfax Terminal, etc.

1) Resources and other considerations

A. Data Storage and Analysis

- Use centralized data platform (e.g., PostgreSQL + GIS)
- Develop dashboards for real-time visualization (Power BI, Tableau)
- Open selected datasets to researchers and startups

Suggestions: Louage & Taxi Data

- Clarify interview logistics: Specify if interviews are random or targeted by route or region.
- Add safety and ethical note: Since drivers are directly involved, consider adding mention of voluntary participation, etc.

B. Budget Considerations

- Local surveyors and data collectors
- GPS devices and sensors
- Software licenses and cloud storage
- Training and workshops

Funding sources: National budget, World Bank, AFD, African Development Bank, EU programs,

C. Ethics and Data Privacy

- Follow **Tunisia's Personal Data Protection Law (Law No. 2004-63)**
- Follow the legal framework governing statistical activities in Tunisia **(Law No. 99-32)**
- Ensure all personal data is anonymized and aggregated
- Inform participants and get consent where needed
-

Suggestions: Ethics and Data Privacy

- Emphasize consent protocols: Clarify how informed consent will be collected (oral, written, app-based).

2.2. Technical details about Household Travel Survey

Population: Households

Area: All the regions

Sampling Method: Stratified Multi-Stage Cluster Sampling

Sampling rate: 0.1% (as a proposal)

Suggestions : Technical details about Household Travel Survey

- Eexplicitly state the approximate number of households this corresponds to in Tunisia (e.g., if 3 million total households, 0.1% = 3,000). This helps contextualize the sample size.
- Add a sentence: "Assuming a national household base of X million, a 0.1% sampling rate yields approximately Y households.

2.2.1. Sampling Method: Stratified Multi-Stage Cluster Sampling

1. Stratification

Divide Tunisia into **strata** based on relevant characteristics such as:

- **Geographic Region**: North, Center, South
- **Governorate** or **Delegation**
- **Urban vs. Rural** areas

This ensures representation across regions and population densities.

2. Stage 1: Selection of Primary Sampling Units (PSUs)

- Define PSUs as **enumeration areas (EAs)** or **neighborhood blocks** (often used in national censuses).
- Select a random or systematic sample of EAs **within each stratum**, **proportional to population size** (PPS sampling).

3. Stage 2: Household Selection Within Each PSU

- In each selected EA, list all households (or use a sampling frame if available).
- Randomly select a fixed number of households (e.g., 10–20 per PSU).
- Use **systematic or simple random sampling** at this stage.

4. Stage 3 : Individual Selection (Optional)

- If surveying only part of the household (e.g., adults only), randomly select individuals within households.

Sample Size Considerations

Depends on :

- Desired confidence level (typically 95%)
- Margin of error (e.g., ±5%)
- Expected variability in travel behavior
- Budget/logistical constraints

A typical national HTS might include **3,000–10,000 households** depending on scope.

Advantages of this Method

- Ensures national and regional representativeness
- Efficient fieldwork logistics (by working in clusters)
- Allows comparisons between urban and rural zones

Example: Suppose you're surveying 6,000 households nationwide:

- **Stratify** by 6 regions (e.g., Greater Tunis, North-West, etc.)
- **Select 100 PSUs** using PPS
- **Survey 60 households per PSU** (100 × 60 = 6,000)

2.2.2. Panel Survey Design for Mobility Seasonality

The main goals are:

- To observe **changes in daily travel patterns** over seasons
- To understand how **holidays, weather, and school schedules** affect mobility
- To track **structural changes** in transport use over time

1. Determine the Survey Frequency

To capture **seasonal variation**, conduct the survey **4 times per year**, once per **season**:

Round	Timing	Purpose
Round 1	January–February	Winter behavior, school term start
Round 2	April–May	Spring travel, Ramadan/Eid periods
Round 3	July–August	Summer, holidays, high tourism
Round 4	October–November	Autumn, return to school/work

We can add a 5th round during **special events** (e.g., Eid al-Fitr, back-to-school, etc.) if needed.

Suggestions : Determine the Survey Frequency

- Add a sentence: "Round timing will be aligned with national holidays and school calendars provided by the Ministry of Education."

2. Maintain a Stable Sample

- **Use the same households** across all survey rounds.
- Ensure contact info and consent are collected in the first wave.
- Replace households only if necessary (e.g., relocation).

Attrition Management :

- Offer **small incentives** to encourage continued participation.
- Use reminders (SMS, phone, email).
- Keep the questionnaire short and consistent.

3. Use Consistent Questionnaire Structure

Each wave should:

- Use **the same core questionnaire** (especially travel diary)
- Possibly add 1–2 **rotating modules** (e.g., public transport changes, new mobility options)

4. Data Structure: How Panel Data Will Look

You'll create a **long-format dataset** with multiple rows per household or individual, like this:

Household ID	Round	Date	Person ID	Trip ID	Origin	Destination	Purpose	Duration
101	1	2025-01-20	A1	1	Home	Work	Work	30 min
101	2	2025-04-15	A1	1	Home	Work	Work	25 min

5. Analysis of Opportunities

With panel data, you can:

- Compare **individual behavior** across seasons
- Model the **impact of season, income, or mode availability** on trip frequency
- Track **modal shifts** (e.g., cars to public transport)
- Identify **mobility inequality trends**

Tools & Tips

- Use **unique household/person IDs** to link data across waves.
- Collect weather and calendar data (school year, public holidays) for context.
- If using CATI/CAPI (computer-aided interviews), store household records in a centralized system.

2.3. Example of a questionnaire for a Household Travel Survey

Section 1: Household Information

1. **Governorate**: _____
2. **Urban or Rural Area** :

   ☐ Urban Area ☐ Rural Area

3. **Household Address (optional)** : _____
4. **Number of People in the Household**: _____
5. **Ownership of Transport Modes (check all that apply)**:

   ☐ Private car ☐ Motorcycle/scooter ☐ ~~Bicycle~~
   ☐ Public transport subscription (e.g., SNCFT, Transtu)

6. **Monthly Household Income Bracket**:

   ☐ < 500 TND ☐ 500–999 TND ☐ 1000–1999 TND

   ☐ 2000–3999 TND ☐ 4000+ TND ☐ Prefer not to say

Section 2: Individual Information (Repeat for each household member)

1. **Car Identifier** : _____
2. **Age** : _____
3. **Gender**:

   ☐ Male ☐ Female ☐ Other

4. **Relationship to Head of Household**: _____
5. **Occupation/Activity** :

   ☐ Employed ☐ Student ☐ Homemaker ☐ Retired ☐ Unemployed

6. **Workplace or School Location** (Neighborhood, City): _____

7. **Mode of Travel to Work/School (Primary)**:

☐ Car (driver) ☐ Car (passenger) ☐ Taxi ☐ Louage
☐ Metro/Tram ☐ Bus ☐ Bicycle ☐ Walking

☐ Other: _____

Section 3: Transport Ownership and Energy Efficiency

1. Does your household own or regularly use any of the following transport modes?

(Check all that apply and specify quantity)

Mode of Transport	Owned (✔)	Quantity	Year of Manufacture	Mechanical power (in Hp or kW)	Fuel Type (Gasoline/Diesel/Electric /Hybrid/Other)
Car (personal)					
Motorcycle / Scooter					
Bicycle					
Electric bicycle / scooter					
Shared or company car access					
Truck / Van (for business)					

2. How often do you use each vehicle listed above (average days per week)?

Vehicle Type	Days/Week Used	Main Purpose (Work, School, Leisure, Shopping, Other)

3. Do any of your vehicles meet any of the following energy efficiency or environmental criteria?

(Check all that apply)

☐ Hybrid or fully electric vehicle ☐ Low-emissions vehicle (Euro 5 or Euro 6 standard)

☐ LPG or CNG fuel ☐ Recently serviced/maintained for efficiency

☐ None of the above ☐ Don't know

Section 4: Travel Diary (Previous Day)

For each household member aged 5 and above, record all trips made from 4:00 a.m. yesterday to 4:00 a.m. today.

Trip #	Departure Time	Origin	Destination	Trip Purpose	Mode of Transport	Duration (mins)	With whom?

Trip Purpose Example :

- Work
- School
- Shopping
- Leisure

Mode Example :

- Car, Taxi, Bus, Metro, Louage, Walking, Bike, Other

Suggestions : **Travel Diary (Previous Day)**

- Add the following codes under the **'Trip Purpose Examples'** column for clarification:

  1 =Work, 2 =School, 3 =Shopping, 4 =Medical, 5 =Leisure, 6 =Religious, 7 =Personal business, 8 = Escorting someone

- **For each household member aged 5 and above, record all trips made from 4:00 a.m. yesterday to 4:00 a.m. today.**

Trip #	Departure Time	Origin	Destination	Trip Purpose	Mode of Transport	Duration (mins)	With whom?	Trip Distance (km)

- Add column: “Trip Distance (km)” to enables emissions and energy calculations.

  Add a “With whom?” column. The following codes will help clarify social transport mapping.

  9 = Alone, 10 = With household member, 11 = With friend/colleague, 12 = With child

Section 5: Attitudes and Preferences

1. **What factors influence your choice of transportation?** (Please rank your top 3)

   ☐ Cost ☐ Time ☐ Comfort ☐ Reliability ☐ Safety ☐ Environmental concern ☐ Availability

Suggestions : Attitudes and Preferences

- Use numbers, not checkboxes, to ensure prioritization. (Numbers 1, 2 and 3)

2. **Are you satisfied with public transport in your area?**

   ☐ Yes ☐ No

If no, why ? _____

3. **Would you consider switching to public transport if improvements were made?**

   ☐ Yes ☐ No

If no, why not ? _____

4. **Would you consider using car-sharing or ride-hailing services more often in the future**

   ☐ Yes ☐ No

   If no, why not ? _____

Section 6: Environmental Awareness and Future Mobility

1. **How concerned are you about the environmental impact of transportation?**

   ☐ Not concern ☐ Slightly concerned ☐ Moderately concerned

   ☐ Very concerned ☐ Extremely concerned

Suggestions : Attitudes and Preferences

- Please select the option that best describes your level of concern.

2. **Are you aware of the effects of car emissions on air quality and climate change?**

   ☐ Yes ☐ Somewh ☐ No

3. **Have you taken any steps to reduce your environmental impact from transportation?**
   (Select all that apply)

   ☐ Walking or cycling instead of driving ☐ Using public transportation

   ☐ Carpooling ☐ Driving a hybrid or electric vehicle

☐ Avoiding unnecessary trips ☐ None

4. **Would you be willing to switch to a more environmentally friendly mode of transport if incentives were provided (e.g., subsidies, better infrastructure)?**

   ☐ Yes ☐ No ☐ Maybe

   If no or maybe, why? _____

5. **How familiar are you with the following future mobility options?**
   (Rate: 1 = Never heard of it, 5 = Very familiar)

Future Mobility Option	1	2	3	4	5
Electric vehicles (EVs)					
Car-sharing (e.g., Yassir, Bolt)					
Ride-hailing apps					
Bicycle-sharing schemes					
Smart mobility/planning apps					

6. **Which of the following would encourage you to use greener transport modes?**
   (Select up to three)

   ☐ Lower cost ☐ Better infrastructure (bike lanes, sidewalks)

   ☐ More reliable public transport ☐ Better safety

   ☐ Environmental awareness campaigns ☐ Incentives (e.g., tax breaks, free tickets)

   ☐ Nothing would convince me

Suggestions : Pilot Project Design

Pilot Project Design – Aligned with National Survey

Constraint Type	Pilot Recommendation (Adapted)
Clarify the **purpose** of the **Questionnaire** More	Collect data for both **Macro-level demand** forecasting and **Micro-level** charging behavior analysis
Spatial Units	Select **2 to 3 governorates** only: e.g., **Tunis (urban), Sfax (semi-urban), and Kairouan (rural)**
Max Distance for Daily Trips	Limit the questionnaire to car owners who drive within **50 km** of each urban center in the selected areas.
Target Group	Focus on: (1) **Fuel car owners**, (2) **Public transport users**,
EV Users	Include **any EV/motorcycle/plug-in hybrid owners** found; target a **minimum of 30–50 cases**
Sample Size	Target **300–500 households** total (e.g., 100–150 per selected governorate)
Behavioral Assumptions	Use current **Fuel Car Trip Patterns**, Fuel Station Use, and Parking Location to Model future EV behavior, with a focus on trip **Start** and **End** points.
Carry out the Questionnaire	**Gas** Stations where drivers stop regularly and Combine with Traffic Census data.
Future-proof Questions	Add **3–5 hypothetical questions** about EV charging, future mode choice, and service expectations
Survey Duration	Limit to **4–6 weeks of data collection** to test logistics, interviewer training, and tools
Zonal Detail	Divide each governorate into **urban core only**; no deep sub-zoning at this stage
Socioeconomic Diversity	Ensure inclusion of **low-, mid-, and high-income households** via basic screening
Institutional Users	Include a **small number (10–15)** of professional drivers, taxi users, or **Company vehicle fleet users**
Behavioral Baseline Questions	Ask about **trip purpose, mode, frequency, parking location, fuel fill-up habits**

Source: JICA_WG2_Comments & Suggestions

Appendix 2- 4

Improve STEG Methodology for Forecasting Electricity Demand Based on EV Penetration Scenarios

Improve the Methodology for Forecasting Electricity Demand Based on EV Penetration Scenarios

To improve demand forecasting methodologies that account for electric vehicle penetration, several aspects were evaluated and STEG tools analyzed by JICA experts.

Indeed, assessing the impact of electric vehicles on future electricity demand requires simulation tools and data on mobility and energy consumption. JICA experts propose a diagnostic framework for STEG studies on the impact of EVs on demand, structured around the following key elements:

- Benchmark Studies and Simulation Tools
- Reviewing STEGs Electricity Demand Forecasting Methodology with EV Penetration Scenarios
- Improving STEG Demand Forecasts through Real-World Data Collection and EV Load Analysis

1. Benchmark Studies and Simulation Tools

The lectures cited by JICA experts provide case study examples that allow conclusions to be drawn regarding the methodologies and simulation tools to be used for each objective of analyzing the impact of electric vehicle penetration on electricity demand. The table below summarizes the use cases for simulation tools encountered

1.1 Spatial Planning Models in EV Demand Forecasting Simulation in Japan

- **EV-OLYENTOR** is a multilayered traffic simulation platform designed to predict where electric vehicles are most likely to run out of battery and to determine optimal locations for fast-charging stations.
- Structured into three analytical layers, the simulator processes **digital map data, traffic conditions, and census information** to replicate real-world commuting scenarios.
- Detailed simulations using EV-OLYENTOR informed Japan's strategic layout for quick-charging stations, recommending grids in urban areas (4–10 km² spacing), stations every 10 km on major highways, and wider intervals on rural connectors.
- Such granular spatial data is vital to model charging demand accurately, as different geographic and usage patterns produce varying load curves. Terrain features like peninsulas or highlands, which affect EV range, also influence station density requirements.

- Thus, spatially optimized infrastructure directly contributes to **forecasting the timing, location, and magnitude of EV power demand**, supporting grid reliability and planning.

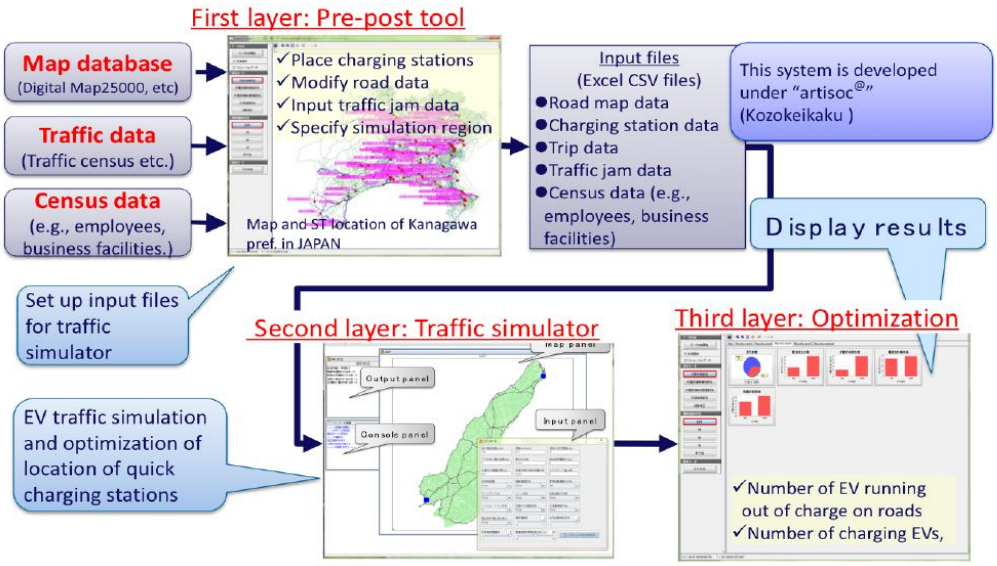


Figure 1: Structure of the EV-OLYENTOR Traffic Simulator with Multiple Layers to Analyze Locations for Quick-Charging Stations for EVs

Source: A Japanese Model Plan for a Quick-Charging Network Based on Traffic Simulation for Promoting EVs, Tomohiko Ikeya et al., CRIEPI and Kozo Keikaku Engineering, 2017.

1.2 EVI-Pro Lite National-Level of EV Demand Forecasting Tools

- **Overview of EVI-Pro Lite:** EVI-Pro Lite is a planning tool developed by the U.S. Department of Energy (DOE) to assist in estimating the number and types of electric vehicle (EV) chargers required, while also forecasting electricity demand resulting from EV charging activities.
- The tool leverages real-world driving data to model different EV adoption scenarios and user charging behaviors. Designed primarily for the U.S., it uses localized data and assumptions but can be adapted for use in other regions with proper customization.
- By simulating infrastructure needs and load impacts, EVI-Pro Lite helps utilities and policymakers prepare for the growth of EVs and plan grid integration strategies effectively.

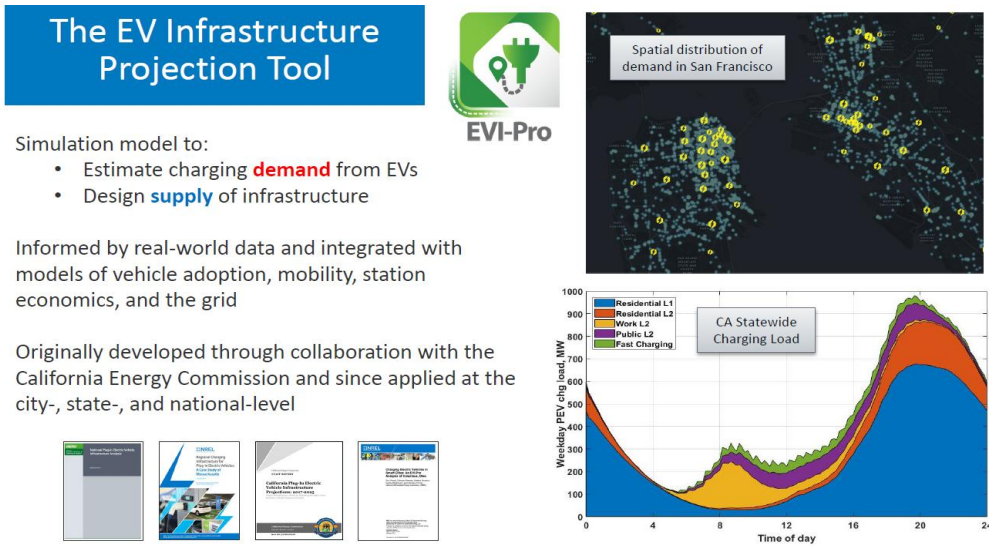


Figure 2: The EV infrastructure Projection Tool

Source: LEVI-Pro Lite Updates Webinar, NRE. Eric W. et al., 2020.

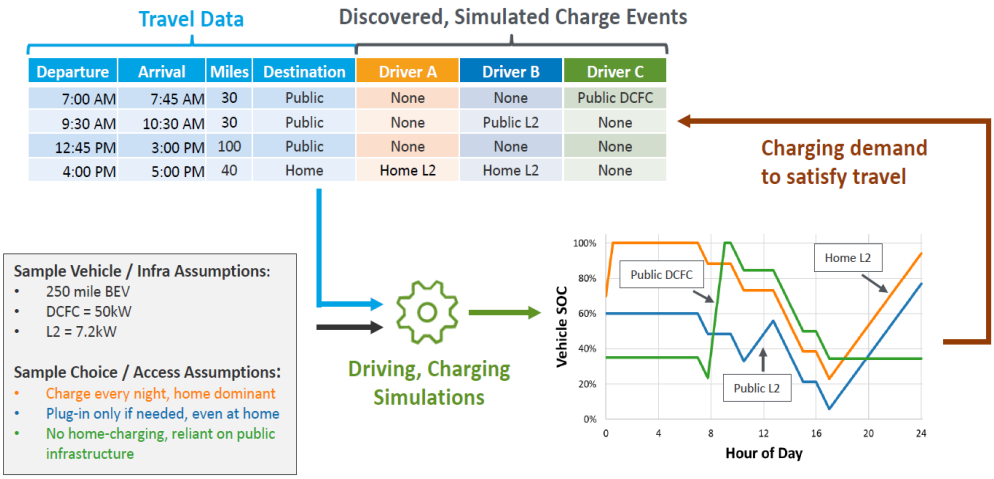


Figure 3: EVI-Pro Driving / Charging Simulations

Source: LEVI-Pro Lite Updates Webinar, NRE. Eric W. et al., 2020.

1.3 IEA EV Charging and Grid Integration Tool

- **The IEA EV Charging and Grid Integration Tool:** is a comprehensive modeling platform developed to evaluate the electricity demand and grid impacts associated with electric vehicle (EV) adoption at both national and local distribution levels.

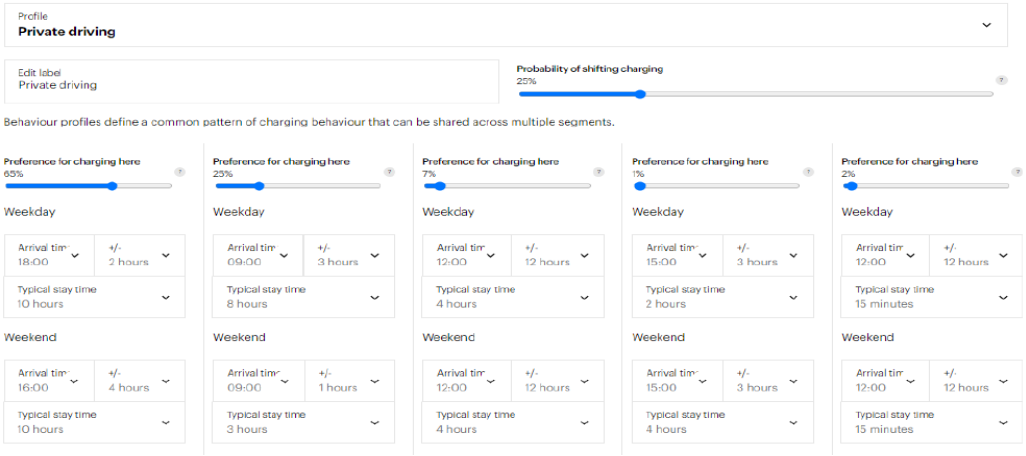


Figure 4: Private Driving Behavior Profile

Source: EV Charging and Grid Integration Tool, User manual and technical note, IEA, 2023.

- **The tool consists of three interlinked modules that capture the multifaceted impacts of EV charging.**
- **Module 1:** simulates weekly EV electricity demand based on fleet composition, battery capacity, driving patterns, and ambient temperature. It allows users to define charging opportunities across multiple locations (e.g., home, depot, workplace) and set preferences based on cost or operational needs. This module evaluates both bulk power and local grid effects, including peak demand contributions and localized stress on transformers or voltage levels.
- **Module 2:** analyzes managed charging strategies—Balanced Charging, Time-of-Use tariffs, and Active Control—to show how load shifting can mitigate peak demand and support renewable integration. By comparing unmanaged and managed profiles, users can assess the benefits of smart charging in terms of grid reliability and flexibility.
- **Module 3:** estimates CO_2 emissions from EV charging by simulating dispatch across the generation mix. It allows users to define installed capacity, fuel types, and emission factors, scaling weekly simulations to annual projections for climate impact assessment.
- While the tool was developed primarily for use in the **United States**, using **U.S.-specific data and assumptions**, its general approach and modeling framework can be adapted for use in other countries if localized data, such as driving patterns, EV adoption rates, and grid characteristics, are incorporated. The tool's flexible design allows for customization to suit specific national contexts, providing valuable insights for global EV infrastructure planning.

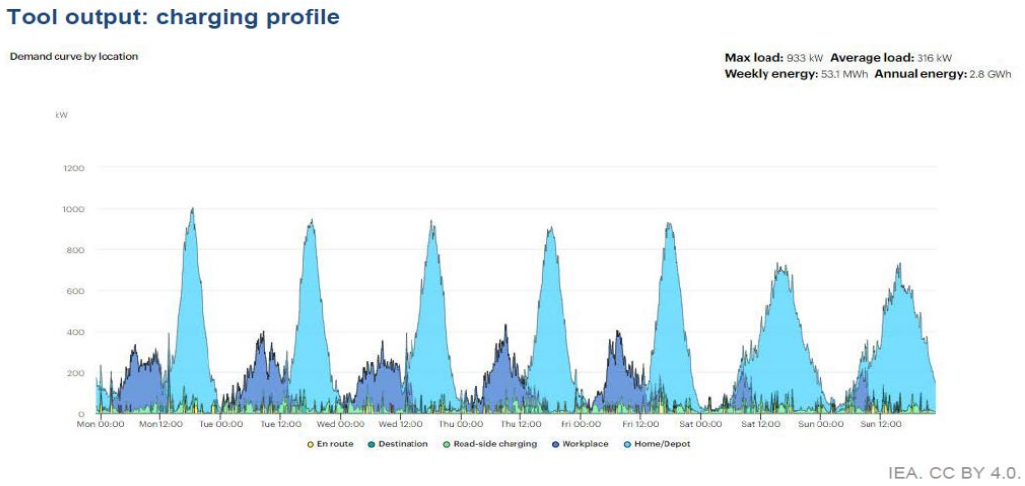


Figure 5: Total Output: Charging Profile

Source: EV Charging and Grid Integration Tool, User manual and technical note, IEA, 2023.

1.4 MAED-IAEA Demand Forecasting Tool

- **MAED-2 (Model for Analysis of Energy Demand):** is a structured, bottom-up energy planning model developed by the International Atomic Energy Agency (IAEA) to support long-term national energy demand forecasting. It evaluates how socio-economic development, demographic trends, and sector-specific factors influence future energy consumption.
- MAED-2 enables users to simulate energy demand across five key sectors: Residential, Commercial, Industrial, Transport, and Agriculture. Energy use is projected at the level of individual services (e.g., heating, cooking, lighting, mobility), allowing for granular analysis of end-use behaviors.
- The model's demand estimates are driven by detailed socio-economic indicators such as population growth, GDP, household size, urbanization, appliance penetration, and vehicle ownership.
- These inputs are used to determine energy needs by fuel type—electricity, fossil fuels, renewables, and heat—under different development trajectories.
- Scenario-based planning allows users to compare the impact of varying assumptions about economic growth, urban transport policies, fuel efficiency, or electrification trends. MAED-2 integrates seamlessly with other IAEA models such as MESSAGE for energy supply optimization and BALANCE for constructing national energy balances.
- While MAED-2 includes transport sector projections, it does not model vehicle technologies, charging infrastructure, or hourly demand impacts. Instead, it estimates total energy use based on **Macro-Level indicators** such as the number of vehicles, vehicle-kilometers traveled, modal shares (e.g., car, rail, bus), and average fuel economy.

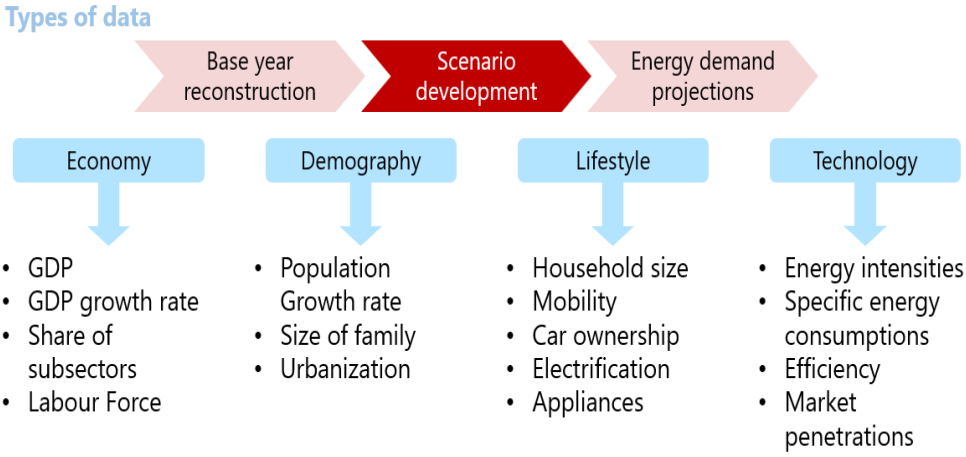


Figure 6: Data Types for Input and Structure

Source: Model for Analysis of Energy Demand Input Data Consistency and Structure, Berdellans, I. et al., IAEA.

2. Reviewing STEGs Electricity Demand Forecasting Methodology with EV Penetration Scenarios in Tunis

The methodology used by STEG to analyze the impact of electric vehicle penetration on total electricity demand focuses on energy demand scenarios and future national load over time horizons ranging from 5 to over 20 years. It relies on combining an electric vehicle charging simulation tool with an energy demand analysis tool. The first tool is derived from the IEA tool (the electric vehicle charging simulation tool was developed within the framework of the GEF-7 global program aimed at supporting countries in their transition to electric mobility), and the second is the IAEA's MAED tool (MAED: Energy Demand Analysis Model). To this end, electric vehicle charging profiles are generated using the IEA tool and integrated into the MAED_EL module using assumptions related to vehicle mobility and energy efficiency.

JICA experts find that STEG's methodology is suitable for planning power systems and that the main possible improvements concern data collection for better calibration of the reference year and more relevant trend assumptions.

3. Improving STEG Demand Forecasts through Real-World Data Collection and EV Load Analysis

3.1 Data collection for EV load simulation

In line with a transition to electric mobility, electricity demand scenarios should be studied using an energy demand analysis model to assess the impact of this mobility transition on energy demand.

The Survey highlights key insights into demographics, vehicle ownership, driving habits, infrastructure availability, and public perceptions.

The goal is to analyse emerging trends, forecast EV penetration, and estimate the electricity demand for EV chargers to inform future planning.

Additionally, to assess the impact of EVs on the grid, supporting widespread adoption across the country and contributing to global sustainability objectives.