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# SMART GRID AND CHALLENGES OF GRID SUPPORT BY E-MOBILITY

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***Abstract***

*This paper explores the role of electric vehicles (EVs) as new grid elements, focusing on the technological and legislative prerequisites necessary for their optimal integration. The widespread adoption of renewable energy sources (RESs) introduces significant unpredictability in energy generation and uncertainty regarding grid capacity to accommodate RES electricity. This necessitates a paradigm shift in network planning to effectively manage these uncertainties. A smart grid (SG) integrates the actions of generators, consumers, and prosumers, relying on advanced metering infrastructures (AMI), two-way communication (such as PLC), advanced energy storage (ES) solutions, data management, big data analytics, and cyber-physical security. These technologies, particularly ES systems, are essential for the effective operation of EVs as new network entities. SG planners face numerous challenges, including establishing criteria for the design and construction of charging stations (CSs) and addressing various legal aspects. This paper also examines modern trends in this field and the impact of traffic electrification on ageing distribution networks (DNs). Are e-vehicles exclusively compatible with smart grids?*

**Key words:** *Smart Grid, e-vehicle, e-storage systems, AMI*

## 1. Introduction

Recent years have seen a power system paradigm shift. In order to cut carbon dioxide emissions, more and more RESs have been integrated into the grid. This significantly changes the system topology from top to bottom, moving it from the concept of several large production units connected to the towards a decentralized structure with numerous distributed RE generators (DG). This new system structure poses challenges to network stability, not only due to the two-way flow of electricity

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but also due to the volatile nature of weather-dependent RES. To address these challenges, smart information and communication technology (ICT) devices are being introduced to automatically monitor and control the power system, which, in conceptual terms, constitutes a SG (Malla&others, 2022). Both power and ICT systems are part of the national critical infrastructure and therefore require to be designed as resilient systems. The term "resilience" can be defined as the ability of a system to "anticipate, absorb and quickly recover from an external high-impact low-probability shock" (Parol&others, 2022).

The integration of data block chain technology into electricity networks makes electricity networks smart and enables their decentralisation. The role of EV as a e-storage network element in SG will be discussed here. Several categories of importance will be defined in the continuation of the paper, highlighting the challenges of implementation in ageing distribution grids.

## 1.1 Smart Grid concept

A SG is an electricity grid that integrates the behaviours and actions of all users connected to it entities (Fig. 1), namely three types of users: generators that produce electricity, consumers who consume electricity, and those who do both, i.e., prosumers. Together, these entities create a peer-to-peer network to ensure efficient electricity distribution, low losses and a high quality and security of electricity supply (European Technology Platform, 2010)1.

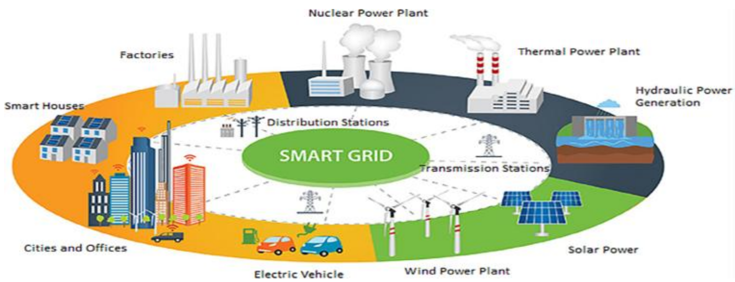


*Figure 3: Smart grid concept2*

The peer-to-peer network eliminates intermediaries in trade between trusted entities, giving buyers and sellers the freedom of preference, choice and price. A smart network is expected to be able to solve more complex problems more effectively and securely, through intelligent monitoring, control, communication and self-healing technology3. One of the challenges in the SG deployment is how to support a communication infrastructure consisting of millions of entities (EVs are one of them) operating and trading in a single market. Energy traceability is also becoming a serious issue. Blockchain data was also used to optimise energy

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1 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0202:FIN:EN:PDF
2 https://www.eolasmagazine.ie/smart-grid-evolution
3 https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group3_first_year_report.pdf

transactions in µGs. In this case, a green certificate is used, which attests that the energy was produced from RES.

### 1.2 Microgrid arhitecture

Microgrids (µGs) consist of various DERs, reactive loads, and critical loads (Fig. 2). They connect to the utility power system through a point of common coupling (PCC). Whether operating in grid-connected or islanding mode, each DG unit is linked to the grid via power interface electronics enabling effective control, measurement, protection, and reconnection of the unit after shutdowns. In grid-connected mode, a µG can exchange surplus energy with the power system. If a power failure occurs, the µG seamlessly transitions to islanding mode to maintain stability for the area it serves. This ensures a continuous supply to critical loads through efficient integration of DGs and load management, which may include load shedding based on predefined protocols. Central µG controllers and local controllers manage this operation.

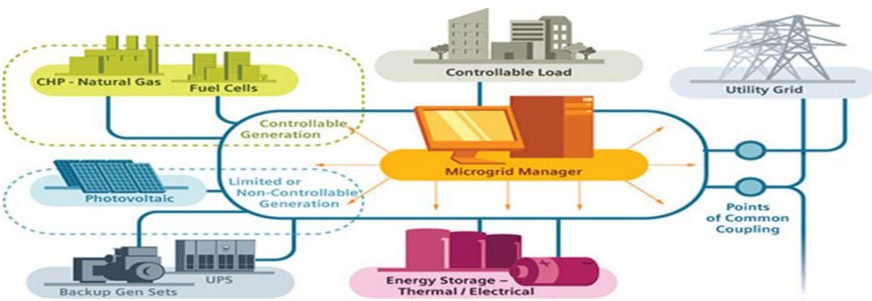


*Figure 4: Microgrid architecture1*

Effective control and coordination of DG within µGs significantly enhance system performance and support sustainable development. As awareness of climate change and socio-economic development grows, µGs are increasingly integrating sustainable energy plants, RES, and energy-efficient technologies that convert waste into energy. Numerous papers emphasize the importance of sustainable energy systems for effective energy management in µGs (Zahraoui&others, 2021, Thirunavukkarasu&others, 2022, Ahmad&others, 2023). Microgrids can be classified based on several criteria: (1) Type of Current, (2) Level of Centralization, (3) Mode of Operation, (4) Number of Phases, (5) Purpose of Utilization, etc.

### 1.3 Electric Vehicle and µG

When grid-connected, EVs can offer a cost-effective solution for electricity storage. Their batteries can be utilized in several ways:

[1] http://content.icicidirect.com/mailimages/Microgrids.htm

- Vehicle-to-Grid (V2G): This technology allows energy from an EV battery to be returned to the grid, enabling charging or discharging based on predefined signals.
- Vehicle-to-Everything (V2X): This encompasses various applications, including "vehicle-to-home" (V2H), "vehicle-to-building" (V2B), and V2G, depending on where the electricity from EV batteries is utilized.

Smart charging technology (CT) facilitates controlled management of EV charging, allowing stored energy to be fed back into the grid to balance production and consumption mismatches.

By 2040, the number of passenger EVs on the road is projected to reach 730 million, with annual lithium-ion battery demand rapidly increasing to approximately 5.7 TWh by 2035 and a cumulative total of 244 TWh by 2050. V2G technology could play a significant role in peak load management. In Germany, if 100% of EVs were V2G-enabled, they could provide 300% more power than the current estimated peak level. Even with just 25% of EVs participating in V2G and 50% availability, they could contribute 40% of the estimated peak load1. With battery storage capacities ranging from 30 to 200 kWh (depending on vehicle size and range of 200 to 700 km), managing tens of TWh of storage capacity becomes essential. Additionally, with charging capacities between 3 to 20 kW, a 0.5 MW PV power plant in an average-sized parking lot could store energy in several EVs, which is typical for such facilities.

When integrated into a μG, excess electricity generated from a RES can be stored in EV batteries, providing an efficient alternative to external ESSs. As the use of RES increases, the power system may become more unstable, necessitating new solutions for energy balancing and storage. Utilizing EV batteries can address this challenge. Traditionally, network balancing relies on rapid adjustments in generator output. However, power regulation can also be achieved through network load management. This approach is particularly effective when inverters are integrated into every photovoltaic (PV) system, allowing for quick responses to maintain system stability. However, the high charger power and the grid challenges that arise during the charging process should be taken into account. The massive presence of EVs will have a dramatic impact on DN's performance if the plan-based sustainable implementation of CSs is absent (particularly relevant for ageing DNs).

## 2. Impact of EV batteries on network operation for different network loads

EVs and their CSs are becoming integral components of DNs. Most EV batteries are charged during daily off-peak periods when electricity demand is lower. However, some EVs may need to be charged during peak electricity price periods.

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[1] Electric Vehicle Outlook 2023, BloombergNEF https://about.bnef.com/electric-vehicle-outlook/

To facilitate rapid charging, high-power chargers exceeding several hundred kWs are often required. This level of power cannot typically be supplied solely from the grid, making it essential to source energy from RES as well. Additionally, utilizing power from EV batteries themselves can be a viable solution. A third option is prompt power supply, though network capacity limitations may arise due to potential congestion. EVs play a crucial role in grid stability, especially during power deficits, as they can provide electricity at the point of consumption. When connected to the grid, an EV's battery can serve as a power source. As more EVs are charged at home or through company-provided or public chargers, they could become significant power sources during short emergency periods when grid power is scarce.

V2G technology allows EV batteries to draw energy from the grid when prices are low and supply it back when prices are high. This capability transforms each EV owner into an energy service provider during battery-to-grid interactions. Furthermore, EV owners can use their EV's battery to power their homes during peak pricing periods, avoiding costly grid energy. Depending on the battery type, the stored energy may be sufficient to power a household for several hours.

As the EV fleet continues to grow, the implications of off-peak battery charging become increasingly significant, potentially leading to rising energy prices during traditional off-peak times. The increasing number of EVs may also drive down costs for "smart" chargers and battery systems, including reductions in system management and grid integration expenses.

## 2.1 Charging stations for electric vehicles

EV CSs can be designed as energy facilities connected to the existing DN, integrated into a µG within a larger SG, or operate autonomously using RES like solar power. Each configuration has its own advantages and disadvantages for both the CS and the network operator. The growing demand for faster charging and increased energy supply to EV's batteries presents significant challenges. This demand accelerates the expansion of charging infrastructure while placing additional strain on the connected network. Achieving this with minimal energy loss and maximum efficiency is crucial for profitability. RES-based CSs, when part of a SG and integrated into a µG, can lower operating and charging costs, reduce GHG emissions, and enhance network performance while enabling new services. µGs that utilize PV energy connect to EV CSs through power converters, allowing the use of renewable energy without storage. However, PV energy is intermittent and requires regulation through the network resources of the connected µG.

There are two types of EV chargers:

- On-board chargers: Built into the EV, these chargers connect directly to an AC outlet, converting AC power to DC for the battery. They have limited power and longer charging times.

- Off-board chargers: These chargers convert AC to DC at the CS, providing high DC power directly to the vehicle's battery. They are more robust, enabling rapid charging and supporting V2G technology.

Despite the advantages of off-board chargers, a significant portion of energy consumed by EV CSs still comes from fossil fuels or conventional hydropower. Therefore, developing EV charging systems in conjunction with RES is environmentally beneficial. However, integrating CSs with PV systems requires substantial space for PV panel installation, often in combination with wind power plants (WPPs, especially vertical WPPs) within a μG.

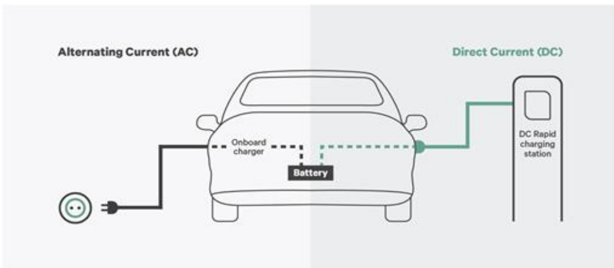


*Figure 5 On-board and off-board chargers – symbolic presentation1*

## 3. Establishment of EV charging infrastructure

To ensure the sustainability of the EV CS system, it is crucial to meet two key criteria: establishing legal regulations and defining spatial positioning and design standards. The architecture of the CS, along with the choice of power source and operational mode (isolated or grid-connected), significantly impacts battery sizing, project costs, and overall performance. When planning the construction of a CS, the following factors must be considered:

1. CT and Connection: Evaluate the CT, EV connection method, operational mode.
2. Rated Power and Supply Method: Determine the rated power of the CS and how it will be supplied with energy.
3. Standards Compliance: Adhere to standards for connecting charging cords, cables, and connectors to maximize performance.
4. Charger Cost and Performance: Understand that the cost and performance of a charger depend on the semiconductor devices used and its topology, which influence the choice and size of the charging system.
5. RES: RES-based CSs can significantly reduce environmental impact and highlight the benefits of RES generation. When connected to a μG, these stations enhance stability and, when paired with batteries, can serve as ES solutions.

Following these factors, the EV CSs design and functionality can be optimized.

[1] https://wallbox.com/en_catalog/faqs-difference-ac-dc

### 3.1 The establishment of entities and regulation of the EV charging market

The legislation in this area should encompass the following key roles:

- Charge Point Operator (CPO): CPOs are responsible for building and maintaining EV CSs. They install hardware from various EV power equipment suppliers and ensure the ongoing efficiency of charging operations. CPOs provide the essential charging network infrastructure and facilitate the connection between the charger and the EV.

- E-mobility Service Provider (EMSP): EMSPs utilize the services of CPOs to manage relationships with EV owners. Their operations heavily rely on CPOs, particularly for real-time system monitoring, control, and customer support.

- Marketplace Operator (MO): MOs play a crucial role in the e-mobility market, facilitating transactions and interactions between CPOs, EMSPs, and EV users.

Together, CPOs and EMSPs are vital participants in the evolving e-mobility landscape, ensuring a seamless charging experience for EV users.

### 3.2 EV charger station location and power optimisation

To determine the best location for a CS certain research must be conducted. Choosing the ideal location is crucial to maximizing the performance of the CS for an expected number of EVs. Several factors influence the placement of CSs, including customer satisfaction. Other important factors concern EV charging demand, characteristics of charging devices, charging fee policy and electricity costs, costs of CS installation, operation, maintenance and land purchase, controlling the duration of the charging process and determining the type of charger or battery replacement options, and some other factors (Abraham&others, 2021).

For CSs location optimization, sophisticated multi-criteria decision-making methods such as MCDM, VIKOR, PROMETHEE, or a combination of these are often necessary (Morocho-Chicaiza&others, 2024).

### 3.3 EV charging infrastructure in an ageing distribution network (DN)

An ageing DN is characterised by several decades of under-investment, a capacity deficit and high levels of energy inefficiency and carbon intensity. Its low-voltage (LV) substations are designed to supply 150 to 300 consumers, with an average connection power of about 15-20 kW three-phase and about 5 to 7 kW single-phase. In the Western Balkans region, the development of these networks has been going on since the end of World War II, throughout the period of greater or lesser investment. The typical transformer (TR) power in urban area is 400kVA (much less in rural). Assuming a typical EV battery power of 10 kV and a household connection load of 10 kV, can be analyzed two scenarios: one without grid-connected EVs and one with them. In the scenario where one in four consumers purchases an EV and charges it at home, with a load simultaneity factor of 0.3, the results are presented (Tab. 1). The increase in EV connections is akin to a rise in consumer demand, leading to evident TR overloads in the EV context. The use of a home peak controller is a palliative solution, as they continuously keep the peak load close to the maximum. This directly can affects the dramatic increase in the simultaneity factor. In the EVs scenario, the load increases by approximately 12%. This is a highly optimistic outcome. In this simplified example, the optimistic outcome is based on favorable assumptions. However, reality is far more complex and nuanced.

*Table 7. Transformer load in two scenarios*

| scenario | TR power (kWA) | number of customers | average customer load (kW) | load simultaneity factor | TR simultaneity power (kW) |
|---|---|---|---|---|---|
| without EVs | 400 | 120 | 10 | 0.3 | 360 |
| | 630 | 200 | 10 | 0.3 | 600 |
| with EVs | 400 | 150 | 10 | 0.3 | 450 |
| | 630 | 250 | 10 | 0.3 | 750 |

However, it's important to note that the power of EV batteries is significantly greater, and ultra-fast chargers operate at power levels comparable to MV/LV TRs. The impact will remain the same, whether the CS charges the EV batteries directly or the empty ones are swapped for full ones when the EV arrives. In the second case, the waiting time is only shortened. Previous analysis of network models including high EV charging demands is essential. Specialized software like SINCAL, DIgSILENT, MATLAB, etc., can be used for network modeling.

Additionally, not having an AMI is the serious obstacle to the implementation of V2G and all other services related to RES and ES. That's why a massive rollout of AMI is the first and mandatory step for any ageing network.

## 4. Conclusions

Insufficient EV charging infrastructure poses a significant barrier to the growth of e-mobility. To overcome this challenge, it's essential to break the existing vicious cycle[1].

To address the urgent need for shorter charging times and the installation of ultra-fast chargers with high power output, it's essential to go beyond relying solely on the existing network. Only RES-based CS can support EV charging effectively. Upgrading the current network to accommodate the growing power demands of chargers is a lengthy process. Additionally, EV's batteries represent a significant potential for ES. Comprehensive legislation is needed to regulate this sector, alongside the development of sustainable design principles, site selection, and operational strategies for these systems. Grid support can be essential to address the potential operational limitations of RES.

Effective planning is essential for transitioning from a traditional DN to one that includes a high presence of EVs. This requires a multi-sectoral approach to identify key corridors for future CSs, involving transportation, tourism, energy,

[1] https://eur-lex.europa.eu/eli/dir/2014/94/oj, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023SC0088

agriculture, and spatial planning. Additionally, regulations should be prepared and adopted to recognize new entities in the electricity market related to e-mobility. These regulations include technical guidelines and methodologies regarding several sectors, and the spatial planning sector is no less important than the energy sector. MCDM can help overcome challenges and reconcile many existing and sometimes conflicting interests. Finally, promoting the use of EVs and implementing sustainable measures will further encourage the shift toward e-mobility.

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