Swedish Electromobility Centre
Vehicle–Grid Interaction

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# Roadmap Theme 5

# Vehicle-grid interaction

## Introduction

With a significantly increasing number of electric vehicles in society, the vehicle fleet will require increasing amounts of electric energy and power. Together with the expected electrification of other sectors, this will have a significant impact on the operation of the electricity system. There is already a debate on, and concern over limitations in transmission capacity in the regional grid into several cities such as Uppsala, Stockholm and Malmö. Thus, there is a need for research on how a ramp-up of electric vehicles can be integrated into the electricity system, including how this will interact with other electrified systems in society. Theme 5 '*Vehicle-grid interaction*' deals with the system interaction between electric vehicles and the electricity supply infrastructure, including the prerequisites and demands for generation, transfer and utilization. Further on, when discussing infrastructure, we refer to physical equipment like the charger but also local energy production, energy storage, transformers, cables and other grid components. Moreover, we include other aspects like communication, authorization, and control systems. The theme covers research on all kinds of electric vehicles on land, water, and air. Although the theme focuses on the interaction between electric vehicles and the power grid, it also includes an outlook into system solutions for supporting the use of fuel cells in electromobility applications.

The theme includes different aspects such as: Vehicle-grid physical interaction including power supply; Vehicle-grid data, communication and security interaction as well as Human/Consumer perspectives. These aspects are strongly related, and a holistic approach is often required to set realistic boundaries to identify problems. Several areas are related to other themes in SEC, and an important role for the theme will be to collaborate with the other thematic areas and to be SECs interface to other competence centers within the power system area.

The 'Vehicle-grid physical interaction' addresses the physical and partly hardware-related needs and abilities necessary for enabling the vehicle-grid interaction. Moreover, the 'Vehicle-supply infrastructure interaction' addresses the system effects of the electrification of the transportation system. An increased share of electric vehicles will likely result in a substantial increase in peak power demand if no action is taken to provide smart integration of electric vehicles in the energy system. There is need for research which can study the interaction between electric vehicles and the electricity supply infrastructure generation, distribution and storage under different assumptions on charging strategies for road and off-road electric vehicles, including conductive as well as inductive charging – static and dynamic. An example of the benefit of the transport fleet electrification is that smart charging (including V2G) can create value for the electricity supply system by reducing the need for investments in peak power and grid infrastructure. This calls for studies on possibilities for sectoral collaborations, such as between utility companies and vehicle manufacturers or vehicle owners. Moreover, there is also a trend showing that an increasing share of electricity supply will be delivered at lower voltage levels. Distributed generation (e.g. solar PV and wind power) can be integrated with hybrid battery systems that combine stationary storage and electric vehicle batteries. Installation of more distributed generation and an increased electrification of transport will impact grid demands and requirements for new power systems electronics. Another important area to be investigated is related to different aspects of charging at higher power levels where there is a need to identify limitations and requirements on additional power supply infrastructure.

In the modern world, there is a need for a lot of data and communication transfer for realizing systems interaction, such as the one between vehicle and grid. Aspects of data generation and processing will need to be investigated, as well as how data is used, making sure that it is done in a safe and data privacy compliant way. By keeping in mind, the data, communication and security aspects from an early stage, the whole (holistic) system can be designed in a more integrated way. Applying a systemic and holistic approach might show the optimal individual parts may not combine to yield the greatest total synergy and value. Hence, research on hardware and data/security should be integrated, not pursued separately.

Nowadays, human and consumer needs, desires, capabilities and limitations are important and crucial aspects to consider for the interaction between vehicle and grid to take place. Therefore, the human perspective needs to be included and understood for a successful design and development of this interaction. Some aspects that will be important for the theme to examine are charging times (user need/desire) vs. charging powers (system capabilities and deployment), the physical interaction (ergonomics), cognitive interaction and interaction with the system as a user, acceptance for new technologies and (charging) behaviors, etc.

It is considered of great importance to add to the theme portfolio projects with an interdisciplinary perspective, addressing different holistic challenges and what the impact will be on the vehicle-system-grid.

## Strategic research areas

Within the theme, there is a need for research projects that are based on models/data that are realistic from both a power system and a vehicle perspective. We also encourage projects with experimental verification. Furthermore, we see a need for studies at different system levels, from individual vehicles to a complete fleet of vehicles. The main question for the theme is to evaluate different charging strategies; when, where, how, and why? Projects within Theme 5 should ideally address several of the following interconnected areas: Vehicle-grid physical interaction including supply; vehicle-grid data, communication and security interaction; Human/Consumer perspective; and Holistic challenges. Four strategic areas that have been identified are: (i) charging at lower power levels, (ii) charging at higher power levels, (iii) charging infrastructure: a system perspective, and (iv) need and use of energy storage in the power system.

## Scope and boundaries

The purpose of the theme is to answer the question on how the interaction between vehicle and power system should be done to maintain a stable power system and at the same time make sure that all vehicles can be provided with intended function. This implies a good knowledge about vehicle user profiles, charging strategies and other energy consumption and power demand in society. The importance of this is further enhanced by the ongoing and foreseen electrification in other sectors, especially in industry. The ambition of this theme is to identify the requirements and demands necessary to fulfil the scope. These requirements include aspects of when, where, and how charging (and discharging) should occur. Both static and dynamic charging solutions should be considered.

Some important scopes of the theme are listed below.

- Interaction between EVs, the electric power grid, and the electricity supply system.
- Limitations imposed on charging due to constraints in the local grid and the vehicle.
- Optimal placement of charging stations (including e-road segments and battery swapping stations).
- Grid stability over time (sub-hour, hour, day, week, month, year).
- Holistic V2G and smart charging, accounting for adverse system effects in vehicle, charger, grid and consumer.
- Quantification of grid reinforcement requirements and investigation of alternative solutions.
- Predictions of future energy and power demands and impact on the power system and on vehicles.
- Stationary storage and renewable energy supply integrated in the charging infrastructure.
- Analysis of current and future policy instruments and regulations. Modification and permitting needed for a successful implementation of electromobility solutions.
- Human/Consumer perspective on smart charging.

Some of the areas of the theme are closely related to the other themes within SEC and we actively encourage cross-thematic projects. As a boundary, specific technical solutions or different charging technologies (hardware) will not be treated within this theme: this is included in thematic area 2 'Electrical machines, drives and charging'. Moreover, Theme 5 does not work with business models, although economic assessments can be included in the research projects.

## Current Trends and Needs

There are several different trends when it comes to interaction between vehicles and grid. One example is smart charging. The basic idea with smart charging is that you can decide when and where a vehicle should be charged. One question which arises is for which actors should smart charging be optimized, i.e., for the EV users, society, vehicle industry or grid owners? Furthermore, do smart solutions which are ideal for all involved actors exist?

Moreover, the power generation landscape is transforming, incorporating more renewables and requiring power systems to accommodate increased variability in electricity generation. There will be a possibility for electric vehicles to support the electricity grid and the energy system so that both EVs and renewable electricity generation have a positive impact on power quality, for example.

A growing number of sectors (i.e., trucks, buses, maritime vessels, aircraft, vehicles used for mining, forest industry, etc.) are facing a shift to electromobility. These, together with an increased use of electric cars, will increase the need for a higher power output from the grid. Therefore, it is necessary to investigate how to achieve a successful integration, based on the requirements and extent of the demand.

Vehicle to grid (V2G) is a concept being tested. With V2G it is possible to use the vehicle's battery pack as a power source for the electric grid: the power flow in the system becomes bi-directional. Other terms related to this concept are: V2L an individual EV battery pack provides energy to a load; V2H (vehicle-to-home) and V2B (vehicle-to-building), where the power flow exchange is limited to the house or the building. The general term V2X (vehicle-to-everything) relates to the communication and information exchange between several objects such as power system, status of other cars, power production etc. Today, there is a lack of clear incentives, communication standards, and business models for V2G.

Another trend that can be observed nowadays is that new actors are emerging. These actors mainly support the vehicle - grid interaction by providing services related to data analysis and measurement, improving the observability of the grid, as well as acting as an intermediary entity between the users and the grid operators.

The manufacturing of batteries is facing an upscaling phase, and the demand is expected to be greater than the supply in the future. Therefore, there is a need for studies where the use of batteries is optimized. Within this theme area, the focus will be to study system solutions where the battery pack can be smaller in size and study solutions that will prolong their lifetime. Such systems could for example include dynamic charging, wireless charging and battery swapping.

Some more identified needs within this area can be classified in:

*EV Charging and Vehicle Technology*

- Vehicle and Infrastructure Assessment: Holistic comparison of BEV, PHEV, and FC(H)EV, including different charging/fueling infrastructures such as ERS and wireless charging etc.
- Charging Strategies and Behavior: Analysis of when, where, how, and why vehicles charge (including user attitudes/behavior), and the role of vehicle autonomy in charging.

*Grid Integration & Flexibility*

- Electrification Integration: Analysis of how to manage a strong ramp-up of EV electrification within the electricity system and grid, focusing on the importance of flexibility measures and energy management strategies.
- Smart Charging and V2G: Optimization and implementation of smart charging and Vehicle-to-Grid (V2G) technologies (including V2H and V2B).
- Grid Impact and Resilience: Investigation of grid resilience, stability, and reliability, and the use of islanded microgrids and Behind-the-Meter DC systems for improved system strength.

*Efficiency, Cost, & Optimization*

- Energy Efficiency and Losses: Quantification of energy losses from the HV/MV grid to the vehicle ("grid to wheel efficiency") and vice versa, with a review of incentives to improve overall system efficiency.
- Cost and Scalability: Analysis of optimal investment for present and future energy/power demands and the ease of scaling charging infrastructure.
- System Improvements: Review of incentives and technical alternatives for continuous improvement in system efficiency and performance.

*Standards, Regulation, and Ecosystem*

- Ecosystem and Stakeholders: Mapping of the eco-system, stakeholders and actors involved in vehicle-to-grid interaction today and tomorrow.

- Standards and Regulations: Examination of standardization to facilitate grid interaction and the role of regulations and incentives.
- Security and Communication: Focus on cybersecurity, data security/privacy (GDPR), and communication protocols (e.g., Peer2Peer, AI) for vehicle-grid interaction.
- Safety and Compatibility: Consideration of safety for vehicles and infrastructure during charging including EMC aspects.
- Other trends: Assessment of the impact of other trends such as autonomous driving, micro-mobility, and alternative technical solutions like fuel cells.

## Forecast

This section lists some key areas expected to develop over the next 5 to 15 years.

**5 years**

- Communication standards for interaction are in place and 2nd generation smart meters, roaming and plug & charge type functionality is rolled out.
- Megawatt charging infrastructure is widespread.
- Chargers and charging clusters can be dynamically controlled by the available power in the grid, based on user preferences.
- V2G is standardized and implemented in commercial products, and financial incentives are implemented although widespread interoperability should not be expected.
- A range of maritime pilots are completed to set new standards and market models.
- Many transformers on all levels have been retrofitted with sensors, feeding data to control centers.

**10 – 15 years**

- High penetration of electric on-road and off-road vehicles in society as well as mature standards and market practice when it comes to technical solutions.
- Ongoing electrification of maritime applications and short distance electric aircraft, together with electrification of harbors and airports.
- Different technologies are used to balance the grid: V2G, battery storage, load shedding, load shifting, etc.
- The flexibility markets have grown and developed on local and national scale, both in terms of volume and number of actors.
- Autonomous vehicles and shared mobility contribute to smart energy management in densely populated areas.