Road map theme 5:
Interaction between vehicles and grid

Introduction

With a significantly increased proportion of electric vehicles in society, the vehicle fleet will require an increased need for electric energy and power. This will have a significant impact on the operation of the electricity system, in particular since an electrification of other sectors such as industry and the built environment is also expected. 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 electrification in society. This theme, theme 5: '*The interaction between vehicles and grid*' includes the system interaction between the vehicles and the electricity supply infrastructure, including the prerequisites and demands for generation, transfer and utilization of power and energy. Further on, when discussing the charging infrastructure, we mean the system between the vehicles and existing grid connection point and it might include other equipment than the charger such as local energy production, energy storage etc. The theme covers research on all kinds of vehicles, such as passenger cars and heavy-duty trucks, but also vessels for air and maritime transportation.

The theme includes four different aspects, as seen in Figure 1: Vehicle-grid physical interaction including power supply; Vehicle-grid data, communication and security interaction; Human/Consumer perspective; and Holistic challenges. These aspects are strongly related, and a holistic approach is often required to set realistic boundaries to identified 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.

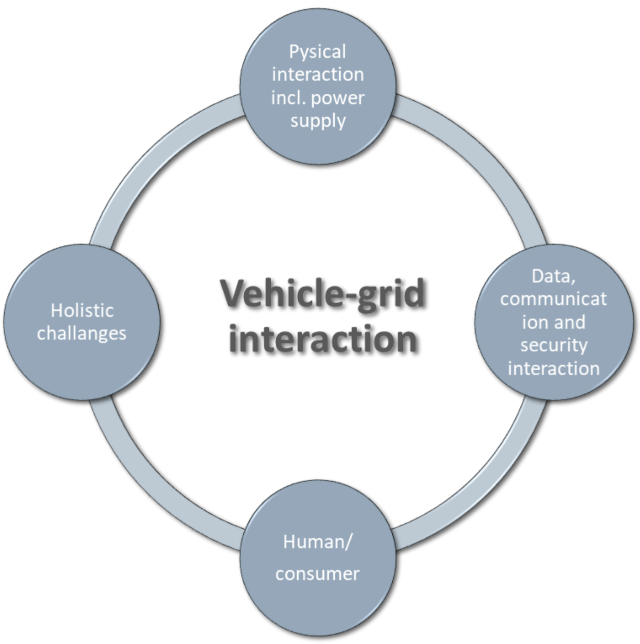

Figure 1: Different aspects related to the vehicle-grid interaction.

The 'Vehicle-grid physical interaction' addresses the physical and partly hardware related needs and abilities necessary for the vehicle-grid interaction. Moreover, the 'Vehicle-supply infrastructure interaction" addresses the system effects of an electrification of the transportation system. With an increased share of electric vehicles, these are likely to result in a substantial increase in peak power demand if no action is taken to provide smart integration of the vehicles (and other electric vessels) in the electricity system. There is need for research which can study the interaction with electric vehicles and the electricity supply infrastructure (generation and distribution) under different assumptions on charging strategies for both light and heavy-duty vehicles, including conductive as well as inductive charging – static and dynamic. An example of an opportunity from electrification of vehicles is that it seems as if smart charging (including V2G) can create a value for the electricity supply system by means of reducing the need for investments in peak power. This calls for studies on possibilities for sectoral co-operations, such as between utility companies and vehicle manufacturers or vehicle owners. There is also a trend in that an increasing share of electricity supply will be supplied at lower voltage levels in the form of both wind power and distributed generation. The latter may involve solar PV- battery systems where the battery can be a combination of stationery and vehicle batteries. These trends will have implications on both system effects, grid demands and requirements for new power systems electronics. Another important area is to investigate different aspects related to charging at higher power levels where there is a need to identify different limitations and identify requirements on additional power supply infrastructure. Other aspects that could also be included in this theme is e.g. energy storages and local power supply, V2G, Microgrids, DC-grids and cross-vehicle-type standardization.

In the modern world there is a lot of data and communication necessary or desired for realizing an interaction such as the one between vehicle and grid. Not only will aspects regarding how data is processed or created be needed but also how it's used and in a safe and data privacy compliant way. To in an early stage have the data, communication and security in mind the whole (holistic) systems can be designed in a more integrated way. When applying system and holistic thinking it can be understood that the best pieces put together are not necessarily the ones with greatest synergy and value creation. Hence it's important to not research the best hardware and the best data/security one by one, but together.

The human and consumer needs, desires, capabilities and limitations are today an important and crucial part for the interaction between vehicle and grid to take place. Therefore, the human perspective needs to be included and understood for the design and development of the interaction between vehicle and grid. Some aspects that will be important for the theme 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.

There is also of great importance to have projects with interdisciplinary perspective that address different holistic challenges and what the impact will be on the vehicle-system-grid part.

Scope and boundaries

The purpose with the theme is to answer the question on how the interaction between vehicle and power system should be done in order 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 profile, charging strategies and other energy consumption and power demand in the 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 different requirements/demands necessary to fulfil the scope. These requirements include aspects on 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:

- Research about the interaction between EVs, the electric power grid and the electricity supply system
- Limitations imposed on charging due to limitations in the local grid and the vehicle
- Optimal placement of charging stations and e-road segments (ERS)
- Grid stability over time (sub-hour, hour, day, week, month, year)
- Holistic V2G, accounting for adverse system effects in vehicle, charger and grid.
- Quantification of grid reinforcement requirements and investigation of alternative solutions
- Predictions of future power demands and impacts on the power system and impact on vehicle.
- Traffic flow modeling including power system analysis
- Automated charging
- Charging of self-driving vehicles
- Local storage and renewable energy in connection to larger charging points or ERS

Some of the areas of the theme is closely related to the other themes within SEC and there will be several projects that also will relate to other theme(s). 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.

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 rasied to this is for whom is should be adjusted to i.e. optimal for the EV user, society, vehicle industry, grid owner, and will it exist smart solutions that will be ideal for all sectors and actors involved?

Moreover, we see a shift in power generation and we are including more renewables and develop a power system that more tolerates variations in electricity generation. There will be a possibility for electric cars to support the electricity grid and the energy system in large so that both electric cars and renewable electricity generation have good reputation.

More and more sectors (i.e. trucks, busses, maritime vessels, air crafts, transports used for mining, forest industry etc.) are facing a shift to electromobility, this together with an increased use of electric cars, will increase the need for a higher power output from the grid. Therefore, there is a need to investigate how this can be done and also to identify what the need looks like.

Vehicle to grid (V2G) is a concept being discussed. With V2G it is possible to use the car's battery as a power source and there will be a bi-directional power flow in the system. Other terms related to this is V2H (vehicle to home) where the power flow exchange is limited to the house and V2X (vehicle to everything) is connected to the communication and means that information from several objects (power system, status of other cars, power production etc) can be used to decide the action of the cars. There are also more terms as used for identifying the communication as V2D (vehicle-to-device), V2I (vehicle-to-infrastructure), V2N (vehicle-to-network), V2V (vehicle-to-vehicle) and V2P (vehicle-to-pedestrian). Today, there is a lack of clear incentives for V2G. However, you can find more identified benefits with V2H (power flow behind the meter).

The manufacturing of batteries is facing an upscaling phase and the demand is expected to be greater than supply of a period of time. Therefore, there will be a need for studies where the use of the battery is optimized (for this theme, study charging solutions where the battery can be decrease in size and study solutions that will increase the lifetime).

Dynamic charging and wireless charging is two other options for charging that can complement and sometimes replace the static plug-in charging.

Some more identified needs within this area:

- Different charging strategies; when, where, how and why?
- Holistic assessment of BEV (battery electric vehicle) vs. ERS(electric road system)-connected PHEV (Plug-in Hybrid Electric Vehicle) vs. FC(H)EV (fuel cell (hydrogen) electric vehicle) including infrastructure.
- LCA including climate impact and other impact categories as well as resource and energy efficiency etc.
- Investigation to expose and quantify energy losses from Infrastructure (i.e. local HV/MV grid) to vehicle (energy storage) and visa-versa, review incentives to improve overall system efficiency. Review any technical alternatives/observation points which would enable continuous improvements.
- Are ERS realistic given the grid today? What would be required to enable widespread installation/use of ERS? Analysis of the economic values of ERS.
- To analyse how a strong ramp-up of electrification can be integrated in the electricity system and the electric grid. This should consider interplay between, and the importance of, different flexibility measures in the grid, where smart charging of EV including V2G are promising options to handle solar and wind variations.
- Energy efficiency – grid to wheel efficiency.
- Cost and scalability – Optimal investment for todays and future demands and the ease of scaling.
- Stakeholders and actors today and tomorrow for the interaction vehicle to grid.
- Impact of other trends – autonomous drive, micro mobility.
- Cross-vehicle-type standardization
- Regulations and incentives
- Energy management & Charging control, Decentralized and self-regulating, V2G
- Commnication: Peer2Peer solutions, cybersecurity, data privacy, AI, improve convenience (move operations and decisions from human to machine)
- Charging strategies for battery optimization (size and service life)

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 verifications. 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? Different areas (Vehicle-grid physical interaction including supply; vehicle-grid data, communication and security interaction; Human/Consumer perspective; and Holistic challenges) can be linked to this and we encourage research projects that addresses several of the areas that are mentioned in the roadmap. Four areas that have been identified are:

Charging at lower power levels

Charging at higher power levels

Charging infrastructure; a system perspective

Need and use of energy storage in the power system

Forecast (5 years, 10 year, 15 year perspective etc)

5 year

-Communication standards for interaction is in place, further developed power tariffs and 2nd gen smart meters, roaming and plug & charge type functionality is rolled out. Better usage of energy and power with functions as asymmetric power consumption. Chargers and charging clusters can be dynamical controlled by the available power in the grid, based on user preferences. V2G becoming clearer, but strongly influenced by learning on local steering & control and how flexibility markets & regulation develops. ERS regulatory & standardization topics handled/ completed. First market/ commercial pilot implemented (but not yet fully delivered?). We will have a range of maritime pilots completed to set new standards and market models. Many transformers on all levels have been retrofitted with sensors, feeding data to control centers.

10 year

-There will be a mix of conductive and inductive charging on the market, V2G is standardized & implemented in commercial products and financial incentives are implemented. Business cases developed for aggregation actors to gross energy market. Standard ERS for commercial application proven or superseded by battery technology improvements & competition from hydrogen+fuel cells. Other transport segments (maritime & aviation) are partially electrified.

15 year

-Consolidation and surviving companies. High penetration of Electric Vehicles in society as well as mature standards and market praxis when it comes to technical solutions. This will lead to a high focus on standard solutions that are proven and accepted. ICE in a higher degree driven by synthetic/biofuels. New energy actors/traders. Peer-to-peer energy trading. More common with carpooling in densely populated cities acting in a timely integrated ecosystem. Heavy commercial road transports electrified – combination of technology solutions. Maritime applications significant electrification. Short distance 400km flight, democratic flights.

Relation between theme areas:

Strategic researcharea	Systemstudier och metoder	Elektriska maskiner, drivsystem och laddning	Energilagring	Elektromobilitet i samhället	Samverkan mellan fordon och elnätet
Charging at lower power levels	x	X	X	X	X
Charging at higher power levels	X	X	X	X	X
Charging infrastructure; a system perspective	X	X		X	X
Use of 2nd life batteries in the power system		X	X	X	X

SWOT analysis: Electromobility and power system

S — STRENGTHS

- **Technology and development**
- Strong in AI, data and communication
- Strong vehicle industry pass.car + commercial veh. + off-highway mach. (+ boats + aviation)
- Battery tech: Northvolt etc.
- Emob research (as ERS projects) at various universities, high quality
- Sweden has a relatively strong electric grid and CO2 neutral electricity production.
- Long engineering experience in both power grid technology development and power generation development.
- Broad technology portfolio

- **Society**
- Innovation and environmental awareness
- Focus on innovation from politics + agencies
- Innovative IT companies, startups
- Huge interest on electrification amongst decision makers
- Strong PRA (Green deal, Paris agreement)
- ISO standards exist to base it upon

- **Collaborations**
- Traditional tight collaboration politics+industry through governmental procurements
- SEC & Co (collaboration academy + industry)

- **Economy**
- Trends in sharing economy
- Still low market penetration, time to fix it!

W — WEAKNESS

- **Technology and development**
- Technology-driven development instead of need-based
- Limitations in voltage levels
- Limitation in power transmission capacity at some locations
- Limitations in load control
- Lead-times for power system expansion
- Academic and industry silo mentality, driven by financing
- Lots of inertia to develop the grid (NSI)

- **Society**
- Conservative countries & cities (slow change)
- Immature standards now (e.g. Island mode, Vehicle to load. Communication and security)
- Culture of bold innovation decreasing, incremental improvements for better shareholder value
- Waiting for the optimal technology (public actor)
- Legal-/Regular Policies not in time (concession)
- Competence in new areas

- **Collaborations**
- Academic silo mentality, driven by financing
- It takes time to build up new collaborations (automotive industry, community, power grid companies)

- **Economy**
- Low market penetration
- Culture of bold innovation decreasing, incremental improvements for better shareholder value

- Other
- Nobody looks wide enough today, ie takes a holistic perspective on the complete system

O — OPPORTUNITIES

- **Technology and development**
- Multimodal transportsolutions, shorter range
- Autonomous vehicles and invisible charging
- Electric energy storage solutions
- Area that can help the power grid
- 2nd life for batteries, whole industry goes for emob
- Have smart power control and grid topology solutions to overcome limitations in the power system.
- Combine expansion of decentralised power production and charging.
- Reduce emissions, more sustainable solutions

- **Society**
- Legal- /Regulation policies
- New types of customers
- New roles (flexibility market, solution model)
- New jobs and innovations

- **Collaborations**
- Cross-industry collaboration (veh.OEM+power+IT) and partnerships
- We are at the beginning of an electrification of several sectors where there is still the opportunity for actors to work together

- **Economy**
- Cheap (local) renewable electricity generation
- New roles (flexibility market, solution model)

- **Other**
- Sweden's leader in sustainable solutions for charging electric vehicles.

T — THREATS

- **Technology and development**
- Local power grid overload
- Cybersecurity
- Time to set the technical solutions and communication
- Power grid limitations, takes long time to fix
- Unregulated technologies that might have a negative impact on SAIDI
- Several sectors will be electrified simultaneously
- High power for charging trucks and busses are needed
- Some charging strategies can have a negative impact on battery lifetime and efficiency

- **Society**
- Bureaucracy on all levels
- Standardization efforts take time (international alignment needed, though)
- EU law prevents traditional coll. politic+industry
- Stranded asset concerns/ legacy (timing issue)

- **Economy**
- Reduced price for fossil fuels
- Low electricity prices (With high amount of production from fossil fuels)
- High electricity price
- Tax models that will be less favorable for EVs
- Investments costs
- Poor regulated responsibility/Peer-to-peer trading

- **Other**
- Dependent on rare earth metals and other limited resources
- Reduced interest in electric cars and electric vehicles