Roadmap – System studies and methods

The requirements are developing continuously in our vehicles, which leads to increased complexity both in the development process and of the vehicle itself, creating a whole set of research and development challenges. The thematic area *System studies and methods* contributes to the development of competitive hybrid and electric vehicles by addressing methodological challenges, i.e. those that cannot be addressed by studying the individual sub-systems in the vehicle. We do this by developing methods and algorithms, necessary for efficient development and for providing hybrid and electric vehicles with the best overall designs and control possible. A central part of our research exploits dynamic models, computational methods and simulation techniques to study system properties and solutions.

Scope and boundaries of the thematic area

The thematic area, System studies and methods, develops methods and algorithms, which are adopted and utilized in a hybrid and electric vehicle setting by exploiting dynamic models, computational methods and simulation techniques. Main topics are mathematical modelling, dynamic simulation, performance analysis, control design, fault detection and isolation, and optimization. The research is focused on methods and analysis related to hybrid and electric vehicles on a *system's level*. This means that questions, which are primarily related to only a single component or sub-system in the vehicle, should generally not be addressed within the System studies and methods thematic area. Another boundary is that basic research to develop general methods and tools is not pursued within the centre, while the adaptation and use of such general methods specifically on hybrid and electric vehicles are. Further, questions which require detailed knowledge of the industrial aspects like business cases, integration in the vehicle or manufacturing processes are not included in the thematic area, as they require insights into confidential information and are more effectively handled by industrial partners on their own.

Interaction with other thematic areas is part of the thematic area activities, as well as interaction with external stakeholders.

Long-term objectives

The long-term objectives concern methods and guidelines to be used by the automotive industry to leverage the research and development within electrified vehicle systems and to build competence within this area. To ensure the usefulness of the results to all parties within the Swedish Electromobility Centre, the objectives should be general in nature and not specific to some topology, solution or part. At high level, two major and over-arching long-term objectives may be recognised:

- To develop effective methods for *model-based systems engineering* that specifically address the needs for hybrid and electric vehicles. Such methods include requirements and systems analysis, as well as design of functions for control and monitoring, calibration, testing and certification, reconfiguration and adaptation etc. The focus for these techniques is to reduce development time and effort.

- To develop methods that support the *engineering of more flexible and complex complete vehicle functions, (and)or transportation systems* emerging as a response to increased demands on energy efficiency, fuel flexibility and other vehicle attributes. The focus for these methods is to support the development on system level.

Trends in the area

There are a number of trends relating to the vehicle itself, such as new concepts and increased energy recovery. The overall trend is “zero emissions”. A trend to achieve this is to put *intelligence* in the subsystems, and there is big creativity to invent new functionality in the subsystems. This often leads to sub-optimal designs, since optimality of subsystems may be in conflict with optimality at the complete vehicle level. Sub-suppliers often have the responsibility for a subsystem. Compared to a few years ago, the complete industry, from OEMs to sub-suppliers are thinking electrification and hybridization as the way to go. To achieve “zero-emissions”, there is an increased demand on subsystem integration, i.e. the internal combustion engine must be collaborating with the electric drive system and the exhaust gas aftertreatment system in order to fulfil a global goal on vehicle or vehicle fleet emissions. And as electrification is a viable solution to achieve “zero-emissions”, onboard complete vehicle energy management is becoming an even hotter topic in the area and is not limited to just energy used for propulsion of the vehicle.

Another huge trend is *“big data”* and vehicles being *connected* to the outside world, providing system knowledge of how the vehicle is used, where it will go and how the traffic situation is ahead. This gives new *optimisation opportunities*, and a lot of functions that are using this knowledge are developed right now. Vehicle manufacturers have already *look-ahead* functions and *cloud information* sharing systems in the vehicles on the market. This gives a nice platform for developing new functionality, such as route management planning, traffic flow control etc.

There are also trends for analysing additional energy flows and components, as well as for analysing the system aspects of the vehicles’ interaction with the surrounding environment, other road users as well as infrastructure.

Strategic research areas

Derived from these trends, the following strategic research areas have been identified:

Hybrid and electric vehicle concepts and control

The area is related to modeling and control of electric and hybrid drive systems with focus on system or vehicle level optimization, including fuel cell powertrains and off-road vehicles. The area aims to develop methods and guidelines for *efficient systems analysis* of different hybrid and electric vehicle topologies, including sub-systems, *with respect to vehicle features, safety and total cost of ownership*. It addresses the coupling between system sizing and control of the utilization with respect to vehicle features and energy management. It also aims to develop methods for optimal control relating to *energy management*; both off-line and real-time methods are considered as well as centralized or distributed approaches. Energy management in this context comprises the complete vehicle; hence, both propulsion and vehicle dynamic system aspects as well as auxiliary vehicle systems are considered.

Thermal management

The area is related to modelling and control of the thermal system of the vehicle with focus on HW/SW co-design and optimization. There is a need for efficient thermal energy management, such as waste heat recovery, complete powertrain thermal management and exhaust gas aftertreatment system design. Apart from the actual problem to convert the heat energy to a more useful energy type, it makes sense to store the energy for later use, because the heat often appears when no extra kinetic energy is needed or vice versa. This makes electrification and thermal management to a great combination for system optimization. Further, auxiliary systems will have a great influence on the performance of the vehicle and should therefore be included in the system analysis and the powertrain control and optimization. The area aims to develop methods and guidelines for *efficient thermal energy management* of different hybrid and electric vehicle topologies with respect to vehicle features.

Communication - Vehicle-to-X

The area is related to information exchange between the vehicle and the infrastructure and other road users. The area also covers how the information can be used for prediction of future driving and also functional architecture for distributed computing. The area aims to develop methods and guidelines for *prediction system design*. This includes methods for information fusion, as well as analysis methods with respect to robustness, availability, reliability and sensitivity concerning prediction data. The prediction system may either be used in predictive control or to “feed” prediction models.

Transport flow modeling and control

The area is related to modeling and control of transport flows with focus on energy usage optimization. Electrification of the transport system can lead to changes in the transport flows and also in the driving behavior. The area aims to develop methods and guidelines for *efficient systems analysis* for transport flow modelling on macroscopic level. Another research topic from a systems perspective looking outside the actual vehicle, is charging and *charging infrastructure*. Methods for design, and especially optimization methods, of how to size, allocate and distribute charging is important questions that are to be addressed in the area.

Driving missions

The last identified strategic research area is related to analysis of vehicle usage. As vehicles become more and more connected to the outside world and also collects data on-board of how it has been used, this provides a knowledge base for understanding or generating driving missions. The area aims at providing understanding in terms of models of drivers and driving missions that can be used for *efficient systems analysis* or *energy management*. The area is not restricted to manually driven vehicles and could also include automated driving systems.