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Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech Division

REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 2a1 Experimental validation of voltage control of inverter interfaced grids in grid-connected mode

Demo site: Aigle

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1. Description of deliverable and goal

1.1. Executive summary

A novel frequency-domain approach is presented towards the control design for parallel grid-connected voltage source inverters (VSIs) with LCL output filters. The proposed method allows one to design the controllers of multiple VSIs in a single step, and inherently attenuates the resonances introduced by the output filters and coupling effects while guaranteeing stability. Performance specifications such as desired closed-loop bandwidth, decoupling or robustness with respect to multi-model uncertainty can be specified through frequency-domain constraints. Furthermore, controllers can be designed in a plug-and-play fashion. The designed controllers are equivalent in structure to multivariable PI controllers with filters. As the control design is based on the frequency response of the system, the algorithm is independent of the model order, which allows the use of large and high-order models. The performance of the method is demonstrated on a relevant example of a low-voltage distribution grid with 5 VSIs, and the results are validated both in numerical simulation using MATLAB/Simulink as well as in power-hardware-in-the-loop experiments.

1.2. Research question

In recent years, the growth of distributed generation, distributed storage and drive loads has led to a significant increase in penetration of power electronics in distribution grids. These devices are commonly interfaced to the grid through voltage source inverters (VSIs) with passive output filters. A desirable filter structure for grid-connected converters is the LCL filter, which exhibits many advantageous features. However, the parallel operation of VSIs with LCL filters introduces new resonance frequencies and dynamic coupling effects into the grid. More power electronics converters may also be added at subsequent stages and their controllers should be designed for a ”plug-and-play” installation without negatively affecting the grid and the operation of the already existing converters. Moreover, distribution grids with relatively large shares of distributed generation are more susceptible to over-voltages, which are commonly prevented by installing additional Line Voltage Regulators (LVRs). These conditions translate into challenges for stability analysis and control design since the VSI controllers have to be robust towards changes in the grid layout, and have to guarantee performance for highly uncertain and time-varying line impedances.

1.3. Novelty of the proposed solutions compared to the state-of-art

The main advantages offered compared to the more conventional existing methods can be summarized as:

• The controller synthesis requires only the frequency response of the plant, which offers more flexibility for obtaining the model compared to methods based on a state space formulation as explained above. This includes also the possibility of a purely data-driven specification of the plant (e.g. from an experimentally measured frequency response).
• The method allows to combine H2, H∞ and loop-shaping performance objectives, resulting in a very flexible and intuitive problem formulation.
• Robustness versus modeling uncertainties and multi-model uncertainty (e.g. changes in the grid topology) is straightforward to consider.
• The method is very scalable and allows the use of very detailed and high-order models without increasing the complexity of the design process.
• Discrete-time controllers are designed directly based on a continuous-time plant model. No controller discretization step is necessary, and time delays can be considered exactly.
• Controllers are fully parameterized, which allows better performance be achieved with a smaller number of tuning parameters. This parameterization encompasses many common structures, such as the multivariable PI controller with resonance filters.

1.4. Description

See https://infoscience.epfl.ch/record/265967?ln=en

2. Achievement of deliverable:

2.1. Date

The deliverable is achieved in 2018.

2.2. Demonstration of the deliverable

The deliverable has been achieved in collaboration of SINTEF Energy Center in Trondheim, Norway. The developed methodology was validated in a hardware-in-the-loop experiment (see Appendix). Validation in a real demonstrator needs the installation and availability of some controllable inverters in the Romande Energie distribution grid.

3. Impact

This deliverable is related to Subtask 1.2: Real-time control strategies for heterogeneous resources at MV and LV. This work has been done in collaboration with SINTEF Energy Center. The results have been accepted to be published in IEEE Transactions on Power Electronics with the following title: Convex Optimization-based Control Design for Parallel Grid-Connected Inverters. The draft of the paper is considered as an appendix for this report.