PhD Public Defence

Title: Modeling, Control and Stability Analysis of high Performance DC Microgrids

Location: Pontoppidanstræde 105, room 4.127

Time: Wednesday 3 October at 13.00

PhD defendant: Renke Han

Supervisor: Professor Josep M. Guerrero

Moderator: Associate Professor Erik Schaltz

Opponents: Associate Professor Dezso Sera, Dept. of Energy Technology, Aalborg University (Chairman)
Mario Paolone, EPFL, Switzerland
Johan Driesen, KU Leuven, Belgium

All are welcome. The defence will be in English.
Abstract:

With the increasing integration of distributed generations with renewable/non-renewable energy sources and energy storage systems in the power grid, microgrid (MG) becomes one of the most promising active distribution networks. Further, the dc MG brings a potential higher efficiency improvement, less power conversion stage, simpler control structure, especially for dc-based sources and loads. Later, the conception of the dc MG cluster is proposed by considering several connected atomic MGs to improve the resiliency of the islanded system. Generally, power electronics converters in dc system are categorized as: grid-forming converter, grid-feeding converter, and grid-supporting converter. In the literature, lots of researchers are focusing on controllers for parallel connected grid-supporting converters to improve the performance in terms of active damping, current sharing and voltage restoration. By comparison, less research are focused on the other two types of converters which are also important for a dc MG in realistic scenario. On the other hand, since the dc system is a time-varying system structure due to the flexibility of the energy resources, the conventional stability analysis methods are disputed, which are based on the global system models. Accordingly, based on hierarchical control structure, this Ph.D. research project aims to design local passive controllers in the primary level and distributed controllers in the secondary level for all the three types of converters to achieve high performances (such as: dynamic response improvement, passivity-based global stability, communication traffic reduction, etc) for dc MGs or MG clusters.

In the primary level, closed-loop bandwidth improvement, dynamic response improvement and passivity-based global stability are taken as main objectives for high performance dc MG and MG clusters. By using Lyapunov-based theory, the controllers for three types of converters are designed according to linear and nonlinear controller design method. Specifically, an inner loop controller is proposed for grid-forming converters by following the step-by-step backstepping design method to improve the dynamics response, especially for constant power load (CPL) disturbances. For dc MG with grid-supporting converters, hybrid droop control strategy is proposed to enhance the maximum supply capability for CPL. For a MG cluster given by the interconnection of atomic dc MGs with ZIP loads, each composed by both grid-forming and grid-feeding converters, a voltage/current Plug-and-Play (PnP) controller is proposed in a decentralized design fashion to achieve global collective stability by guaranteeing local stable. For PnP controller and hybrid droop controller, they can provide passive characters for systems directly by testing the bode diagrams of system output impedances. In addition, the proposed backstepping controller can also provide passive characters by a small modification. Thus, all the proposed controllers can be operated together for different converters in a MG or MG cluster without compromising the global stability according to passivity-based theory.

With guaranteed global stability in the primary level, the steady-state performance should be improved further by designing controllers in the secondary level. First, for proposed dc MG clusters, a leader-based distributed secondary controller is proposed for grid-forming and grid-feeding converters achieving both voltage and current tracking regulation. Then, for dc MG with grid-supporting converters connected by different line impedance, a distributed nonlinear controller combined with the event-triggered-based communication strategy is proposed to achieve accurate current sharing with significantly reduced the communication traffic. Furthermore, once the line impedances differences in system are large, the trade-off effect between accurate current sharing and voltage consensus regulation is serious. It is analyzed and solved by the proposed compromised secondary controller, including containment-based voltage controller and consensus-
based current controller, to achieve compromised control between the two objectives. Lastly, the same control conception is extended to the ac MG solving the similar problem between accurate reactive power sharing and voltage magnitude regulation.

The modeling about proposed controllers in both primary and secondary level are developed. Based on the models in the primary level, the control parameters are characterized by explicit sets of inequalities, which means the stability and passivity can be guaranteed by choosing the parameters in the sets. Based on the models in the secondary level, the impacts from different control parameters on the system are analyzed by pole-zero loci or eigenvalue loci. The analysis results provide basic guidelines for designing parameters for the proposed controllers.

In order to verify the effectiveness, performance and comparison of all the proposed control schemes, hardware-in-the-loop (HiL) simulations and experimental studies are conducted in a lab scale setup in MG laboratory at ET-AAU.