DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title: Novel Control Strategies for Parallel-connected Inverters in AC Microgrids

Location: Pontoppidanstræde 101, room 23

Time: Tuesday 18 October 2016 at 13.00

PhD defendant: Yajuan Guan

Supervisor: Professor Josep M Guerrero

Moderator: Assistant Professor Laszlo Mathe

Opponents: Professor Francesco Iannuzzo, Dept. of Energy Technology, Aalborg University (Chairman)
Professor Ricardo Quadros Machado, Universidade de Sao Paulo, Brazil
Associate Professor Helena Martín, Polytechnic University of Catalonia, Spain

All are welcome. The defence will be in English.

After the defence there will be an informal reception in Pontoppidanstræde 111 (coffee room).

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Abstract:

Concerns regarding power supply security, environmental issues, and the liberalization of electricity markets have led to a new trend of generating power locally at the distribution voltage level instead of the conventional centralized power generation system. Microgrid (MG) has become one of the most promising active distribution networks. They are typically equipped with power electronic interfaces (PEIs) and controlled to provide the required flexible operation and to maintain the specified power quality and energy output. With regard to multi-PEIs in parallel, the power droop control method has been commonly adopted in the last decade as the decentralized control in MGs. However, this approach has several inherent drawbacks, such as slow dynamic response, active/reactive power coupling, and sensitivity to line impedance.

This project proposes a novel autonomous current sharing control strategy for paralleled voltage-controlled inverters (VCIs) in AC MGs to provide faster transient response, more active/reactive power decoupling sharing, and wider application ranges for different line impedances than the conventional power droop controller. And then, develop a complete small-signal state-space model for the proposed controller in order to analyze the stability and parameter sensitivity. Furthermore, a hierarchical control is developed, including primary, secondary, and tertiary control levels that are differentiated based on the proposed novel primary current sharing control strategy in various applications. These applications include grid-connected mode and discharge rates balancing control for energy storage units. In addition, control strategy design and frequency/voltage stability analysis of multi-source hybrid MGs in remote areas are other research issues addressed in this project.

This thesis starts by investigation of a simpler and faster autonomous current-sharing controller, which consists of a synchronous-reference-frame (SRF) virtual resistance (VR) loop, an SFR phase-locked loop (PLL), and a proportional-resonant (PR) controller in a voltage control loop. The proposed control strategy provides instantaneous and independent direct and quadrature currents sharing for paralleled VCIs. In contrast with the conventional droop control, there is no need to calculate active/reactive powers. An integrated small-signal state-space model for the two parallel VCIs with the proposed controller is developed. Root locus shows lower sensitivity of the parameters over system dynamics and larger stability margin compared with those of droop control. For a seamless transition between islanded mode and grid-connected mode, an appropriate hierarchical control is proposed for the SRF-VR-based novel primary control strategy.

Considering the slow transient response and high parameter sensitivity provided by the droop-based coordinated state-of-charge (SoC) control, as well as the absence of a balanced discharge rate control methods for AC MGs, a coordinated secondary control strategy is proposed based on the presented autonomous current-sharing controller to balance the discharge rates of ESSs in islanded AC MGs. The coordinated secondary controller can prevent overcurrent incidents and unintentional outages in distributed generation (DG) units by regulating the power outputs of the DG units according to their SoC values and ESS capacities. A dynamic consensus algorithm-based distributed secondary control scheme is also proposed in this project to consider the risk of single point of failures (SPOF) caused by a centralized controller. This scheme achieves not only distributed balanced discharge rate control, but also high reliability, expandability, and flexibility because of its distributed control architecture. A detailed discrete state-space model with the proposed SoC coordinated controller is developed by considering the discrete nature of the dynamic consensus algorithm.

The technical features of a multi-source hybrid MG make it suitable for supplying power in remote areas. To achieve a stable parallel operation of a hydropower station and a photovoltaic (PV)-battery system

with different nominal power capacities, inertia, and control mechanisms, a hierarchical control scheme for an islanded PV-battery-hydropower hybrid MG is proposed. The proposed control strategy provides stable and complete decoupling power control between the hydropower station and the PV-battery system. The interaction behavior between these two units during disturbances can be effectively mitigated. An integrated small-signal state-space model for both the hydroelectric power and the PV-battery system is developed to analyze the frequency and voltage stability of the hybrid MG.

Consequently, in order to verify the effectiveness and performance of the proposed control strategies and modeling methods, hardware-in-the-loop simulation studies and experiments on a multi-three-phase inverter-based platform are conducted in an intelligent MG laboratory. The proposed controller is expected to be implemented in real applications to provide superior performances. The generalized modeling methods, with verified correctness and accuracy, can give insight view of the distributed control scheme and the impact of high level control on system dynamics.