PhD Public Defence

Title: Coordinated Control and Stability Enhancement of Direct Current Shipboard Microgrids

Location: Pontoppidanstræde 111, auditorium

Time: Tuesday 13 November 2018 at 13.00

PhD defendant: Zheming Jin

Supervisor: Professor Josep Guerrero

Moderator: Associate Professor Sanjay Chaudhary

Opponents: Professor Remus Teodorescu, Dept. of Energy Technology, Aalborg University (Chairman)
Pavol Bauer, TU Delft, The Netherlands
Manuela Sechilariu, Université de Technologie de Compiègne, France

All are welcome. The defence will be in English.

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

In recent years, direct current (DC) distribution technology-based solution has become an emerging choice for shipboard power system (SPS), especially for those where electric propulsion is needed. By using DC distribution, the fuel efficiency could be greatly improved by enabling variable-speed operation of diesel engines. At the same time, emerging power sources such as fuel cell and energy storages (e.g. batteries, supercapacitors, flywheels, etc.) can be easily installed. In this context, DC SPS become a perfect example of DC microgrid in the real-world engineering. This project is to introduce and to investigate suitable control methods for DC shipboard microgrid onboard future electric marine vessel.

According to the classification societies' prediction, driven by the ever-stricter emission regulation rules and the deployment of new emission control areas, low-emission power source will play a much more important role in the future ships, nevertheless, conventional diesel engine will still be widely installed. Therefore, the new SPSs will be more complicated which require proper coordinated control strategy for multiple power sources. In addition to that, due to the unique fuel efficiency characteristic of diesel-electric generation, the commonly used droop based proportional power sharing strategy of land-based microgrids may not offer good fuel efficiency. To meet these challenges, a re-designed hierarchical control strategy for DC shipboard microgrid is proposed. In the new proposal, the power sharing of diverse power sources onboard a ship is according to their different characteristic instead of their power rating. On the basis of the proposed power sharing methods, technical solutions to achieve fuel efficiency management and system-level voltage restoration are also discussed, thus forming a comprehensive coordinated control solution for DC shipboard microgrid with improved fuel efficiency.

In addition, the stability of DC distribution system is a huge challenge. Due to the fact that a majority of power generated onboard an electric ship will be consumed by the vessel's propulsion system, the high-power non-linear active load may interact with the controllers of source-side power electronic converters and cause instability issues. Therefore, additional stability analysis and control method is needed. In order to analyze the impact of using different control methods on system stability margin, comparative admittance-based analysis among different voltage control strategies is conducted. The two categories of control methods used: (1) impedance-type control (including the most commonly used dual-loop voltage control and the conventional droop method using virtual impedance loop); (2) admittance-type control (i.e. current-based droop control) are modeled and compared.

Inspired by this modeling work, control methods for enhancing stability of DC shipboard microgrid is proposed. First, a stability enhancement that can be adopted by both dual-loop voltage controller and conventional voltage droop controller is proposed, in which specially designed negative series virtual inductor (NSVI) is introduced to cancel part of the instinct impedance of the dual-loop voltage controller. With properly designed NSVI, the output impedance of source-side converter can be modified, thus improving its capability feeding high-power nonlinear active load. The design procedure of NSVI is also discussed.

In addition, control method that can improve the performance and stability margin of admittance-type droop controller is also investigated. Due to its different nature compared to impedance-type control method and its inherent convenience to achieve parallel structure, virtual capacitor that connected in parallel to virtual resistor is proposed as a second degree-of-freedom. By adding virtual capacitor accordingly to conventional virtual resistor, the output impedance and the system-level inertia could be modified at the same time. As a result, due to the virtual inertia injection function of the proposed method, both transient response and stability margin of the system can be modified.
To validate the effectiveness and performance of proposed methods, simulations and experiments are carried out using multi-converter DC microgrid setup. The results demonstrate the effectiveness of proposed control methods in real-world applications.