DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title:	Proof-of-Concept on Next Generation Hybrid Power Plant Control
Location:	Pontoppidanstræde 111, Room 1.177 / Online
Time:	Thursday 10 September
PhD defendant:	Lennart Petersen
Supervisor:	Professor Florin Lov
Moderator:	Assistant Professor Daniel-Ioan Stroe
Opponents:	Associate Professor Tamas Kerekes, Dept. of Energy Technology, Aalborg University (Chairman) Professor Claudio Adrián Cañizares, University of Waterloo Department of Electrical and Computer Engineering, Canada Paul Thøgersen, PowerCon A/S

All are welcome. The defence will be in English.

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Abstract:

The rapidly increasing share of variable renewable energy in power systems has actuated research and development on so-called hybrid power plants (HPP) that combine wind, photovoltaic and storage assets as a physically coupled power-generating facility. From the viewpoint of a wind power plant developer, these hybrid solutions can decrease the levelized cost of energy (LCOE) and help enter new markets for wind power to increase global renewable penetration further. Grid-integrated HPPs can enhance the capability to participate profitably in various electricity markets and to provide grid ancillary services. In rural and remote areas, the potential benefits of a consumer-directed HPP solution are related to grid investment deferral and substitution of costly diesel generation. In such off-grid HPPs, the lack of a dominant voltage source and the high level of variable renewable power and fluctuating consumption is challenging for the control system which must ensure both stable, reliable, secure as well as economical plant operation.

This PhD project is focussed on investigating a configurable, scalable and modular off-grid HPP concept which includes the system architecture, control and operational strategies and real-time interoperability between assets. The specific aim is to improve existing and develop new methods for plant sizing, control design and tuning, power and energy management as well as control verification. An vital contribution to elevate the state-of-the-art is to take a holistic approach by examining the mutual effect of the various design stages, which is required to achieve a proof-of-concept on the plant control system.

In the first part, a list of high-level use cases and the required functions for the operation of HPPs, in general, is suggested, according to particular business objectives. The main body of the work is devoted to off-grid HPPs that are designed for kW-scale community applications and composed of wind turbines, photovoltaic systems, battery energy storage system and diesel-powered gensets. Overall, the developed tools and methods in this thesis are intended to be suitable to larger plant capacities and modifications in asset portfolio, performance requirements or grid interface.

A new methodology to configure generation and storage modules and a scalable plant layout based on the estimated load demand is proposed. The sizing algorithm incorporates both active and reactive power constraints as well as the occurring power losses. The compliance of the proposed configuration architecture with state-of-the-art overcurrent protection techniques is assessed through a post-fault analysis applied to a benchmark HPP.

An essential contribution of this project is a model-based design procedure that entails the required building blocks to obtain a stable power management system. A practical guidance is given on dynamic modeling of the plant assets, which utilize state-of-the-art control mechanisms, and the modular composition to an overall HPP model. State-space and discrete-time domain models are developed in parallel to (i) verify the linearized system representation, (ii) carry out comprehensive assessment studies for both small-signal and large-signal stability, (iii) design and parameterize the voltage and frequency control system in all feasible operating states, (iv) evaluate control algorithms through accelerated offline simulations as well as real-time hardware-in-the-loop (RT-HIL) testing.

An operational strategy based on the load following principle is advanced by taking into account the forecast uncertainties of renewable generation and load demand. The impact of applying various prediction intervals on the resulting system cost is evaluated.

A suitable power dispatch function is developed by considering the operational schedules and the bandwidth of the voltage and frequency controller. The proposed algorithm is robust to modifications in plant layout and grid parameters. The results show its capability of compensating for the variability of

renewable generation by properly sharing the active and reactive power among the available units and maintaining the battery state-of-charge within the design limits.

The operational performance of off-grid HPPs during N-1 contingencies is studied. An emergency control function is designed for the central coordination of load and generation shedding to prevent system blackout. The implications of reliable plant operation on the initial system design stage are exemplified.

The interoperability of the plant control system is demonstrated through a state machine-based architecture which describes the coordination between various power and energy management functions during normal and abnormal system conditions. Finally, control verification through a RT-HIL test platform examines the plant's performance in the presence of communication infrastructure. Moreover, an extended 24-hour test scenario addresses the impact of renewable power fluctuations on battery cycling, which in turn affects its lifetime and the resulting system cost.