Helmholtz Young Investigator Group

Hybrid Networks: a multi-modal design for the future energy system

General information:

Applicant

Dr.-Ing. Giovanni De Carne, Institute for Technical Physics, Male, 31, 09.05.2018.

Assignment KIT-section

Young Investigator Group (YIG) Preparation Program fellow.

Assignment KIT-section

Bereich III, Institute for Technical Physics

Field of study and Helmholtz-program

Energy System Design – Topic 2: Digitalization and system technology

„Host Institute at KIT“

KIT, Institute for Technical Physics, Mathias Noe, Mathias Noe.

International Experience

I pursued my bachelor and master studies in Electrical Engineering at the “Polytechnic University of Bari”, Italy, while I joined from February to July 2013 the Distributed Electrical Systems Laboratory at École Polytechnique Fédérale de Lausanne, Switzerland, for the development of my master thesis on control of active distribution networks, which results have been published [C27]. I was an invited researcher from July to September 2017 at the School of Electrical and Computer Engineering at GeorgiaTech, Georgia, US, working on the multi-modal modelling of asynchronously-connected grids by means of quadratic modelling approach, whose results have been published [C15]. My international experience is further enhanced by numerous international co-publications with world-wide universities: National Technical University of Athens, Greece; GeorgiaTech, USA; Aalborg University, Denmark; University of Nottingham Ningbo, China; University of Padova, Italy; University College Dublin, Ireland. I held tutorials, invited talks and lectures in European and American conferences (PowerTech, ECCE Asia, ISGT Europe) and universities, such as Iowa State University, US, and Leeds University, UK. Refer to my CV for further details.

Leadership Experience

During my PhD at Kiel University, I was the Team Leader of the “Grid Control” group at the Chair of Power Electronics (6 PhD students, 2 Post-docs), where I led the research and laboratory activities. I was in charge of milestones in industrial projects, such as ENSURE and LV-ENGINE, interacting with industrial partners. I directly supervised the research and publication activities of 2 PhD students, whose methodologies are under consideration of industries (i.e., ABB), and the work of 5 bachelor and 4 master thesis students. I’m currently the Team leader of the “Real Time System Integration” group of ITEP, composed of 6 researchers, coordinating the research activities in the Energy Lab 2.0 and writing research projects for further expanding the team.

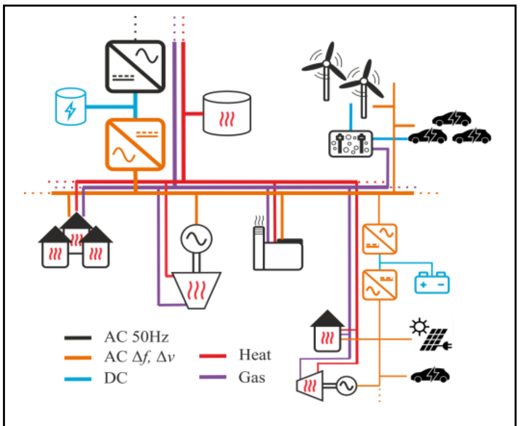

Fig. 1 – Hybrid Networks concept

Information about the Project:

Abstract / Intent/ Goal

This project will take a leap forward in the design of the future energy system, by increasing the power and energy density of the energy system with a massive power electronics and control adoption in multi-modal networks. The project will develop the Hybrid Network concept, including a power electronics-based non-synchronized connection with the main network, that enables a smart control of the fed electrical network, and multi-modal controllers, that permit the coordinated use of more energy layers (Fig. 1). This topic is of critical importance to the Helmholtz Program "Energy System Design", where, in the initial external review of the program, it was explicitly requested to think "out-of-box", and to focus on cross-sector interactions, on power electronics solutions, and on non-synchronized grids. As a unique experimental setup, a multi-modal power hardware in the loop will be realized for the first time to validate the proposed approaches, with the clear goal to make the KIT a world-wide leader in the topic. This project is only possible at KIT given the one-of-a-kind Energy Lab research infrastructure. Two major industrial players in this area, OPAL-RT and Maschinenfabrik Reinhausen, have ensured their support in the project (see attached letters of interest), that shows a strong industrial interest in the proposal, while further companies (ABB, Siemens, Rolls Royce) are involved in present joint project applications.

Formal and Scientific Requirements (short)

To achieve this ambitious goal, this project will address all the most important points in the system design: modelling, control, protection, energy management, and experimental validation. The project is structured in 5 work packages (Fig. 2): WP 1 and WP 2 will run the first three years of the project, while the WP 3 plans 3-years long activities starting from the results of WP 1 on 3rd year. WP 4 follows the outcomes of WP 2 for two years. WP 5, dedicated to the experimental validation, runs for the whole project (5 years).

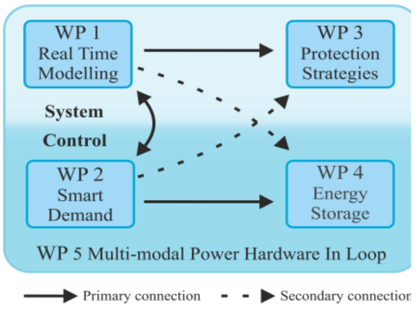

Fig. 2 Structure of the Work Packages

WP 1. Real time modelling of hybrid networks

The current state of art in modelling energy systems focuses either in developing electrical components models for real time systems applications, neglecting or simplifying the multi-modal aspect, or in modelling complex, large multi-modal networks in simulation, that do not take into account the networks dynamics.

This work aims to introduce a multi-modal modelling approach for a digital real time simulator, targeting high simulation accuracy with reduced computational time. As a first step, the future network requirements and challenges are identified, and a multi-modal network benchmark proposed. The second step is the multi-modal network modelling approach with reduced computational time, and it will be realized in close cooperation with Prof. Benigni, FZ Jülich, and with the support of the digital real time simulator company OPAL-RT. As a final outcome, the developed models are implemented in large (German and European level) networks, together with the young investigator group led by Dr. Brown at the IAI.

WP 2. Smart demand control

The electric decoupling by power electronics offers the possibility to supply the hybrid network with voltage amplitude and frequency independently from the main power system. This enables to shape the consumption of voltage- and frequency-dependent loads, playing with the hybrid network frequency and voltage. This concept, that I introduced in my previous works with the name of on-line load control [J11], enables a rapid power control in the network through controlled voltage and frequency variations.

This work package will develop such a smart demand controller, considering different load topologies and characteristics, with the aim to transform the hybrid network into a fully controllable resource. The final outcome will be the services provision to the network, in particular frequency control and system stability enhancement in low and extra-low inertia conditions. The added value to this activity will be given by the Energy Lab 2.0 research facility, that offers an extensive network of load measurements (Living Labs, Bioliq). Such a set of resources allows extensive investigations of the load response during voltage and frequency changes, and of the performance of the smart demand control in realistic network conditions.

WP 3. Hybrid networks protection systems

The hybrid networks, thanks to the power electronics electrical decoupling, can clear faults faster than any mechanical actuators, offering high operation safety standards. Despite these advantages, it is well known that hybrid network grid-forming converters have no overload capability and thus cannot provide the needed fault current to trigger the classical protection system.

This work step addresses the protection requirements for hybrid networks, considering the short circuit current limitations of the grid-forming converter. This investigation will cover different levels of protection intelligence, depending on the future presence of fast communication, the high integration of distributed generation, and the availability on the market of solid-state breakers. This work package will be supported by the cooperation with Maschinenfabrik Reinhausen, considering its industrial experience in designing and controlling grid-forming converters. As an outcome of this work step, the requirements for future protection systems in hybrid networks will be determined.

WP 4. Sector coupling energy storage solutions

The higher power variability, caused from an increasing share of renewables and electric vehicles charging points, will require in the future energy system of faster and larger energy reserve availability. While electrochemical storage and load control offers fast response to power unbalances, they have limited energy capacity. The use of sector coupling can help to overcome this limitation. Having larger energy density but slower dynamics, sector coupling is complementary to the use of electric and electro-chemical energy storage solutions.

This work package develops new energy control solutions, to optimally coordinate the stored energy among different energy layers, focusing on power and energy dynamics (slow vs. fast power unbalances). The outcome will be a controller that enables the self-regulation of the hybrid network energy storage, making it energetically independent from the main network on long time windows (days or weeks).

WP 5. Multi-modal power hardware in the loop system

Power hardware in the loop systems enable the testing of new technologies in realistic conditions in lab, coupling the hardware under test with large-scale simulated networks by means of a power amplifier. Despite the benefits, possible instability behaviors of these loops can arise, due to system delays. More work is needed to assess the system accuracy, particularly for full-scale hardware (e.g., MVA), and to enlarge the testing possibilities to more energy layers.

This working step develops a new multi-modal power hardware in the loop system, aiming to interface the electrical, heating and gas networks. The activity of this work step will be carried with the 1MVA power hardware in loop setup developed in the Energy Lab 2.0 facility, enabling the performance assessment of full-scale hardware. The work step outcome will be the realization of interface algorithms, for the in-loop connection of components from different energy layers, and stability evaluation tools for multi-modal power hardware in loop systems. This activity will be supported by OPAL-RT, focusing on the development of the stability evaluation tool and its experimental verification.

Communication structure:

The communication plan targets the scientific community, publishing in international journal and conferences, and the industry, holding seminars and tutorials in national (Hannover Messe), international (CIRED, CIGRE) fairs, and participating in CIGRE and IEEE working groups. The national-level power hardware in the loop workshop (50 attendees), held in KIT ITEP/IEH every year in November, will be used as the main reference point for advertising the project results to German companies in the field. As an outcome of the project, an industrial PhD course (2/3 days) will be organized on the multi-modal networks modelling and power hardware in loop systems.

Financial plan

Considering the existing large experimental infrastructure of Energy Lab 2.0, this proposal focuses the budget on research personnel more than on materials. Two PhDs and one Post-doc have been planned each year, with the exception of year 3, where 4 PhDs are needed, to close the first 3-years and open the last 3-years activities. The other costs are limited to small consumables, that we may require during experiments, and costs related to publication and conference fees.