

Ph.D. in Information Technology: Theses Defenses

January 23rd, 2019

Room Seminari - 10.00 am

Le Anh DAO – XXX Cycle

“Microgrids Energy Management with a Hierarchical Distributed Model Predictive Control Approach”

Advisor: Prof. **Luca Ferrarini**

Abstract:

The dissertation addresses the problem of management and coordination of energy resources in a typical microgrid, including smart buildings as flexible loads, energy storages and renewables. The overall goal is to provide a comprehensive and innovative framework to maximize the overall benefit, while still accounting for possible requests to change the load profile coming from the grid and leaving every single building or user to balance between servicing those requests and satisfying his own comfort levels. The user involvement in the decision-making process is granted by a management and control solution exploiting an innovative consensus-based distributed model predictive control approach with coordination. In addition, a hierarchical structure is proposed to integrate the distributed MPC user-side with the microgrid control, also implemented with an MPC technique. The proposed overall approach has been implemented and tested in several experiments in the laboratory facility for distributed energy systems (Smart RUE) at National Technical University of Athens - NTUA, Athens, Greece. Simulation analysis and results complement the testing, showing the accuracy and the potential of the method, also from the perspective of implementation. On the other hand, special attention was also put into the work of estimating the production of Renewable Energy Resources (RESs) in general or photovoltaic in this dissertation. Specifically, short-term and medium-term predictions of the day-ahead generated power (GP) of a photovoltaic plant using predicted regional solar radiation (SR) are concerned. In this work, different predictors are developed, which are then combined with the weather forecast service using ensemble methods. Afterwards, under a similar ensemble framework, the impact of the accuracy in the prediction of meteorological variables on the quality of the GP prediction is evaluated. The validation of the approach is performed by using a pilot PV plant and several meteorological stations situated in Northern Italy.

Hafsa FAROOQI – XXXI Cycle

“Design of Collaborative Eco-Drive Control Algorithms for Train Networks”

Advisor: Prof. **Patrizio Colaneri**

Abstract:

In today's age, green transportation remains one of the most important topics of research. The main goal is to promote vehicle technologies and driving styles which are energy efficient and environment friendly. In this thesis, the main focus is on the Energy Efficient Train Control (EETC) or eco-driving strategies of railways. For this purpose, two main research paths have been explored. The first research direction is associated with a single train control problem, where the control problem is to find the best driving strategy for the train to go from one stop to another, given an optimal timetable. EETC strategies can be either fully automated (ATO) or serve as an advisory system to the driver (DAS) for the purpose of assisting drivers in following an energy efficient driving style. For this purpose, three control strategies using Model Predictive Control (MPC) have been presented. In the first two strategies, shrinking horizon techniques have been combined with input parametrization approaches to reduce the computational burden of the control problem and to realize the nonlinear integer programming control problem which arises in the DAS scenario, while the third strategy is based on switching MPC with receding horizon. All the strategies have been tested on the official simulation tool CITHEL of our industrial partner Alstom, and the obtained results in comparison with the existing techniques have proven to be more energy efficient.

The second research direction falls under the paradigm of collaborative eco-drive control strategies, involving multiple trains belonging to a substation network. The main aim is to use the energy regenerated by the braking trains through collaboration among the trains connected and active in the network. In this case, three strategies to decide the collaborative law have been presented along with the extensions from the single train control strategies presented in the first part of the thesis. For the design of collaborative laws, techniques such as manual supervision, substation modeling and dissension based adaptive laws with concept similar to Markov chains have been used. The strategies have been validated with simulation examples. Finally, comparisons of energy efficiency with and without collaboration have been presented, which show the advantage of using the developed collaborated laws.

Stefano Marelli – XXXI Cycle

“Analysis and Development of Electrochemical Model-Based State Estimation Algorithms for Li-ion Batteries”

Advisor: Prof. **Matteo Corno**

Abstract:

Lithium ion (Li-ion) batteries are the most widely adopted technology for electric mobility and consumer electronics, thanks to their ability to store and deliver electric energy more efficiently and effectively than other chemistries. However, costs, performance limits and safety concerns are aspects that still require investments and research efforts. Since fully electric or Battery Electric Vehicles (BEVs) are still seen as a costly solution by consumers, less onerous solutions like Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are more appealing choices. In these vehicles the battery pack is compact, because it is not the main or the only source of energy onboard, thus entailing less initial cost for the batteries. This

puts even more attention on battery performances: a smaller battery is typically required to stand higher powers, compared to its size, than those required to larger BEVs batteries. Given the non-negligible costs and the need for compact yet high-performance solutions, batteries need to be exploited to their limit; a conservative approach would be too costly both for companies and customers. Unfortunately, Li-ion batteries are chemically unstable systems, that require Battery Management Systems (BMSs) to be operated safely and efficiently. The BMS continuously monitors and controls the battery states, such as: temperature, current, voltage, amount of remaining energy, and battery degradation. Many of these states cannot be directly measured; one of the key functions of the BMS is therefore to provide an estimate of these states. The more accurate this estimate is, the closer the battery can be exploited to its fundamental limits, which allows for an efficient and cost-effective utilization. Accurate state estimation and physical insights into cells behavior are enabled by electrochemical models. In the present thesis, two physics-based electrochemical and thermal models are implemented with efficient formulations, namely a Single Particle and Thermal Model (SPTM) and a Pseudo 2-Dimensional and Thermal (P2DT) model. These models describe the dynamics of lithium concentrations and temperatures at different levels of detail. The parameters of the former model are identified experimentally on a commercial Li-ion cell. The latter model is implemented by solving the algebraic constraints on the states via a model decomposition and a control-oriented coupling of the equations. The SPTM is used to develop a sliding mode observer, to estimate lithium concentration inside the model particles from the measured terminal voltage. An analytic computation of the gain matrix allows to enforce mass conservation in the cell; an extremely efficient, yet robust observer is obtained. The State of Charge (SoC) estimation error converges to less than 2.5%. Also, this model is used to design a backstepping observer, which is another computationally efficient solution. Thanks to the inclusion of bulk thermal dynamics, this observer is validated with experimental tests, showing less than 2% SoC estimation error; importantly, local concentrations and bulk temperature estimates are provided by the observer. The P2DT model is first used, without thermal dynamics, to develop an Unscented Kalman Filter (UKF), for which observability issues are solved via a soft-constraint on total lithium mass, and computational burden is reduced by more than a factor 3 with a parallel computation implementation. This approach gives SoC estimation errors of less than 5% in realistic conditions, and local concentration errors of less than 3%. With the inclusion of distributed thermal dynamics, a Dual Unscented Kalman Filter (DUKF) is designed, again with a soft-constraint on lithium mass and a parallel implementation. This structure not only allows to estimate the SoC with less than 1.5% error and the local concentration with less than 4% error, but also to estimate the temperature in any point of the cell with an error of only 0.2°C, under currents as large as 50C and noisy measured voltage.

PhD Committee:

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