Ph.D. Position 2024:

"Modelling and control of large second life batteries for Smart Grid Application"

Supervisors

ESTP: Dr. Asma ACHNIB (aachnib@estp.fr), Dr. Hichem BENZAAMA(hbenzaama@estp.fr)

GIPSA-lab/Grenoble INP-UGA: Prof. Oliver SENAME (olivier.sename@grenoble-inp.fr)

VITO/EnergyVille: Dr. Khiem TRAD (khiem.trad@vito.be)

Location

The Doctoral Research will be performed mainly at the premises of VITO (Belgium) and short visits to ESTP (Paris region), and GIPSA-lab (Grenoble) are possible.

Duration

This thesis is based on a fixed-term appointment for a period of three years, starting as soon as possible.

Keywords

Energy storage, Lithium-ion battery, Battery Management Systems, battery model, Smart grids, Modelisation, Control

Context

The electricity sector holds a considerable share of the responsibility for global carbon emissions. Under the pressure of policies aimed at reducing these emissions, Renewable Energy Sources (RES) are rapidly being integrated into the electrical grid [1,2]. However, this transition to RES presents a major challenge to electrical grid operators, namely, maintaining the balance between production and demand [3, 4, 5], while evolving towards smart grids [6, 7]. As a result of these developments and their impacts, the demand for various types of energy storage for applications on different timescales is constantly increasing.

As electric vehicle (EV) batteries typically last 8-10 years, it's estimated that around a million batteries will be retired from EV applications in the EU by 2030. The end-of-life management of EV batteries is currently regulated by the EU Battery Directive, ensuring 100% collection of decommissioned batteries. Given that these batteries may retain up to 80% of their initial capacity, estimates suggest that second-life batteries, repurposed for stationary applications, could amount to 80GWh/year in Europe by 2030 [8]. Repurposing this attractive large volume of batteries faces however some challenges like the trending price drop of the new batteries, the big spread in the EVs battery pack design, and the lack of second-life quality and performance standards. Moreover, innovative approaches to battery design and repurposing methodologies could optimize the utilization of retired EV batteries in the energy storage landscape. By addressing these challenges and maximizing the potential of second-life batteries, stakeholders can advance sustainable energy practices and bolster the resilience of the electrical grid.

Energy storage systems based on lithium-ion (Li-ion) technology have the capacity to serve as flexible energy sources [9]. They enhance the stability of the smart grid and contribute to providing ancillary services such as peak shaving, outage protection, and grid power quality control [10]. Lithium-ion batteries are energy storage systems that operate on the principle of intercalation. They function as closed systems [11] with very few measurable state variables, which makes the precise monitoring of their condition and the maintenance of their safe operation particularly complex. Typically, voltage, current, and temperature measurements are used to determine or estimate all other battery parameters, such as State of Charge (SOC) and State of Health (SOH) [12]. Therefore, a precise understanding of their behavior under various operating conditions, along with adequate modeling, is essential to ensure their optimal performance.

While accurate modeling of battery packs for energy applications has been relatively limited until today [13], it is crucial to advance our understanding beyond the traditional perspective of treating batteries as ideal DC voltage sources [14] or relying solely on mathematical modeling techniques [15]. To achieve this, it is essential to consider the complex interplay between the battery unit itself and the battery management system (BMS) [16]. The BMS, consisting of both hardware and software components, plays a pivotal role in overseeing the charging and discharging processes of the battery, ensuring its dependable and safe operation. Moreover, the BMS performs critical functions, including cell balancing and thermal management of the battery pack. Given the inherent complexity of Lithium-ion battery operation and their variability according to operating conditions, it is imperative to develop more sophisticated models that take into account the non-linear aspects and complex dynamics of batteries, to enable more accurate and responsive control of these systems [17, 18].

Objectives

The main objective of this PhD is to develop novel methods for modelling, identification, and control of large second-life battery packs in view of smart grid application. This is motivated by the potential to significantly enhance the reliability and quality of the electrical grid. In a smart grid, there’s a continuous flow of information between utilities and consumers, allowing real-time communication about electricity prices and usage. By seamlessly incorporating these batteries into our advanced control and estimation software for battery management systems, we can harness their latent potential to further optimize grid performance. This dynamic

Environment offers exciting opportunities, such as energy arbitrage, maintaining electricity reserves, and aligning power supply with fluctuating demand through the deployment of grid-connected energy storage systems.

The aim is to demonstrate that significant performance improvements can be achieved by designing control and estimation algorithms for the battery management system that accounts for variations among the batteries within the pack and including the integration of second-life batteries. It is important to emphasize that the ultimate goal is to experimentally validate the efficiency, performance, and accuracy of the proposed methodologies. These experiments will be conducted using the smart grid test bench available at ESTP in France, as well as batteries available at the VITO/EnergyVille advanced battery testing lab in Belgium.

The principal steps of the proposed work are outlined as follows:

- **Objective 1- Battery Model Development** The objective is to review the existing literature on modeling lithium-ion battery packs, especially those dedicated to decommissioned batteries. The focus is on identifying the main aging mechanisms, associated safety risks, various characteristics, and the management systems linked with battery packs to develop an accurate and comprehensive battery model.
- **Objective 2- Battery Model Development** Developing an accurate model serves as the foundation for designing effective control strategies, predicting battery performance, and ensuring the overall reliability of the storage system. A hybrid model will be developed, incorporating an Equivalent Circuit Model (ECM) as well as a physics-based model to ensure more accurate results in both SOC estimation (using the ECM model) and SOH estimation (physics-based model developed by VITO).
- **Objective 3- Tests, Validation and Specifications**
    - Design of experiments on both platforms.
    - Model validation.
    - Specifications for control & estimation.
- **Objective 4- Upscale the battery model from cell level to a large battery pack** It is essential for accurately representing the behavior of second-life batteries within the context of a smart grid, as large packs contain batteries with varying characteristics. This process involves considering the interactions between individual cells and the overall performance of the battery pack, given that large batteries are constructed with different modules featuring different SOH and technologies.

  Objective 5- Control Strategy Design Considering the inherent complexity involved in the operation of Li-ion batteries, it becomes crucial to develop advanced controlstrategies specifically customized for smart grid applications. These strategies are designed to enhance battery pack performance, improve efficiency, and prolong battery life. Methods such as robust control will be proposed to ensure performance, robustness and reliability of the solutions.

- **Objective 6- Experimental validation** - Implementation of the proposed model and control strategies. The developed model and control strategies will be implemented on suitable test benches available at ESTP, France, and VITO, Belgium, as well as in real-world scenarios, following the specifications given at step 3.

Required skills

We are looking for a highly motivated and scientifically excellent candidate with a master's degree, an engineering school diploma, or any equivalent degree in control/electrical engineering. The candidate should possess a great problem-solving attitude, innovative analytical thinking, and strong communication skills. Applicants should also have a good knowledge of Python or MATLAB.

Application procedure

To apply, please send an email to aachnib@estp.fr, hbenzaama@estp.fr, olivier.sename@grenoble-inp.fr and khiem.trad@vito.be. Please include the following documents:

1. CV with contact details,
2. Bachelor and master transcripts (including list of courses with corresponding grades) for all the university years,
3. A summary of (or an e-link to) your master thesis,
4. Name and email of two references.

References

[1] J. Cochran, T.Mai, and M.Bazilian "Meta-analysis of high penetration renewable energy scenarios." Renewable and Sustainable Energy Reviews, pp. 246—253,2014

[2] M. Giacomarra and F.Bono "European Union commitment towards RES market penetration: From the first legislative acts to the publication of the recent guidelines on State aid 2014/2020." Renewable and Sustainable Energy Reviews, pp. 218—232, 2015

[3] Y. Chen et al., "Security-constrained unit commitment for electricity market: Modeling, solution methods, and future challenges," IEEE Transactions on Power Systems, pp. 1–14, 2022.

[4] B. Mohandes et al., "A review of power system flexibility with high penetration of renewables," IEEE Transactions on Power Systems, vol. 34, no. 4, pp. 3140–3155, 2019.

[5] A. A. Shakoor et al., "Roadmap for flexibility services to 2030," Poyry and Imperial College London, Report, 2017.

[6] "EPRI-DOE of Energy Storage for Transmission and Distribution Applications," EPRI, and the U.S. Department of Energy, Palo Alto and Washington, CA and DC, 2003, EPRI-DOE no. 1001834.

[7] D. Manz, O. Schelenz, R. Chandra, M. d. R. S. Bose, and J. Bebic, "Enhanced Reliability of Photovoltaic Systems With Energy Storage and Controls," Tech. Rep., National Renewable

Energy Laboratory, 2008

[8] M. Abdel-Monem, O. Hegazy, N.Omar, K. Trad, P.Van den Bossche and J.Van Mierlo, Lithium-ion batteries: Comprehensive technical analysis of second-life batteries for smart grid applications. 2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe)
[9] S. Vazquez, S. M. Lukic, E. Galvan, L. G. Franquelo, and J. M. Carrasco, "Energy Storage systems for transport and grid applications". IEEE Trans. Ind. Electron., vol. 57, no. 12, pp. 3881–3895, 2010.
[10] D. Ton, G. H. Peek, C. Hanley, and J. Boyes, "Solar Energy grid Integration Systems—Energy Storage (SEGIS-ES)," Sandia National Laboratories, 2008, Program Concept Paper.
[11] M. T. Lawder et al., "Battery energy storage system (BESS) and battery management system (BMS) for grid-scale applications," Proc. IEEE, vol. 102, no. 6, pp. 1014–1030, 2014.
[12] M.l Lakkis, O. Sename, M. Corno and D-B. Pietri, Combined battery SOC/SOH estimation using a nonlinear adaptive observer. 2015 European Control Conference (ECC)
[13] Y. Wang, J. Tian, Z. Sun, L. Wang, R. Xu, M. Li, Z. Chen, A comprehensive review of battery modeling and state estimation approaches for advanced battery management systems, Renewable and Sustainable Energy Reviews 131 (2020) 110015
[14] P. J. Chauhan, B. D. Reddy, S. Bhandari, and S. K. Panda, "Battery energy storage for seamless transitions of wind generator in standalone microgrid," IEEE Trans. Ind. Appl., vol. 55, no. 1, pp. 69–77, 2019.
[15] M. Castaneda, E. Banguero, J. Herrera, S. Zapata, D. Ospina, and A. J. Aristizábal, "A new methodology to model and simulate microgrids operating in low latitude countries," Energy Procedia, vol. 157, pp. 825– 836, 2019.
[16] T. Stuart, F. Fang, X. Wang, C. Ashtiani, and A. Pesaran, "A modular battery management system for HEVs," in Proc. SAE Future Car Congr., 2002, 2002-01- 1918.
[17] K.B. Hatzell, A.Sharma and H.K. Fathy. A survey of long-term health modeling, estimation, and control of lithium-ion batteries: Challenges and opportunities
[18] T. Wang, Commande robuste pour une gestion énergétique fonction de l'état de santé de la batterie au sein des véhicules hybrides, Ph.D. thesis, Université Grenoble Alpes (ComUE) (2013)