PhD fellowship at IMT-Atlantique, Nantes (France)
Control-oriented hybrid modeling of coupled multi-carrier energy systems

IMT Atlantique is a technological university and international research center affiliated with "Institut Mines Telecom". IMT Atlantique conducts research in digital technology, energy, and environment. The Department of Energy Systems and Environment (DSEE, **GEPEA UMR CNRS 6144**) conducts research in process engineering related to bio-resources and environmental technologies through three research teams: Water Treatment Air Metrology (TEAM), Energy / waste Recycling and Emissions Processing (VERTE), and Optimization - System - Energy (OSE).

PROMES ("Processes, Materials and Solar Energy"), a CNRS own research unit (UPR 8521) under agreement with University Perpignan Via Domitia (UPVD), rallies about 170 people around a unifying topic: solar energy and its promotion. Its multidisciplinary research activities are structured along three thematic axes: Materials for Energy and Space (MEE), Next Generation Solar Power Plants (CSPG) and Storage and Solar Chemistry (SCS). In the CSPG thematic axis, both the modeling and advanced automatic control of solar energy-related systems, in particular using artificial intelligence, are addressed.

HyMES is a 5-year research project within the PEPR TASE framework that brings together seven academic partners (GEPEA, LAPLACE, ISIR, IES, G2ELAB, PROMES, CEA-LITEN). The main objective of the project is to investigate hybrid modeling solutions as a mean to tackle the growing spatial and temporal complexity of multi-energy systems and networks.

Context:

Multi-carrier Energy Systems (MES) play an important role in the energy transition as they enable the integration and coupling of diverse energy sources and carriers. These systems contribute to the decarbonization and sustainability of the energy system by fostering flexibility and sector coupling. The flip side of the coin is that MES make the entire energy system more complex and, as a result, difficult to control. Due to high complexity, the development of accurate and computationally lightweight models is a hot research topic.

In the literature, two classes of models exist. On one hand, mechanistic models are capable of accurately capturing the behavior of the systems and require little amount of data for their calibration. However, their implementation requires significant computational effort, which limits their usability for real-time applications. On the other hand, data-driven models do not require much computational effort, but a very large amount of historical data is needed for training. In addition, generalizing these models to previously unseen conditions is challenging. Exploring hybrid simulations is a promising research path that remains understudied in the scientific literature (for energy issues). Hybrid modeling refers to the combination of physical models and data-driven models in several ways which include both "Simulation-Assisted Machine Learning (SAML)" and "Machine-Learning Assisted Simulation (MLAS)". Thus, hybrid modeling intends to reduce complexity compared to mechanistic modeling and to reduce the amount of data needed by pure ML-based models for the training process.

Position:

The main objective of this PhD project is to propose new control-oriented hybrid modeling strategies for small-scale energy systems that combine energy conversion and storage technologies and involve different energy carriers. This will entail combining simplified mechanistic models with artificial intelligence (AI) techniques to enhance the accuracy and the predictive capabilities of the models while preserving their explicability. The specific objectives are:

- Define and model a benchmark case using a pure mechanistic approach and identify the limits of physical modeling for the control of energy conversion and storage systems.

- Investigate different hybrid modeling strategies, including substituting all or parts of physical models with ML, parameters identification, coupling ML and physical models, or using ML for model simplification and reduction.

- Develop hybrid modeling strategies for reducing and simplifying the mechanistic models.

- Develop hybrid modeling strategies for improving the robustness and reliability of energy conversion and storage system models.

- Address the challenges of combining systems modeled by heterogeneous approaches with different degrees of hybridization. Identify the optimal degree of hybridization for energy conversion and storage system models maximizing performance (generalization), while managing complexity.

- Use hybrid modeling to handle different temporal scales (e.g., electrical and thermal temporal scales).

- Investigate data selection and preprocessing methods for hybrid modeling.

- Evaluate the performance of the hybrid models using synthetic data extracted from the physical models. Such an evaluation will rely on the assessment of KPIs dealing with accuracy, computational cost, and data requirement.

Background and skills:

The applicant should have either a background in mechanical or energy engineering with proven experience in developing machine learning models or a background in machine learning with proven experience in modeling energy systems.

The applicant will demonstrate curiosity, analytical thinking and capacity to be a creative force.

Excellent mastery of algorithmics and scientific programming will be a very important selection criterion. Good knowledge of one or more machine learning frameworks is strongly recommended.

Duration: 36 months

Salary (informative only): Gross annual salary > 25k€

Employer: IMT Atlantique - DSEE

Location: IMT Atlantique, campus of Nantes

Collaboration: PROMES and HyMES project partners

Contact:
To apply, send a single pdf file including a detailed CV, a cover lette and a full list of publications (if applicable) to the following e-mail addresses:

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