Hybrid Modeling for Smarter Energy Systems: Physics Meets AI

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The transition toward carbon neutrality is driving the emergence of energy systems that are increasingly complex. To integrate fluctuating renewable resources, these systems require need to offer greater flexibility and deeper thanks to storage technologies, demand side management and greater coupling between different sectors. Optimal design and operation of these systems is now a necessity, and must rely on model-based approaches to tackle this growing complexity. However, conventional physics-based models are often too computationally expensive for large-scale optimization and real-time operation, while purely data-driven models require vast amounts of data and suffer from limited trustworthiness, robustness, and explainability.

Hybrid modeling, where physics-based knowledge is combined with machine learning models, offers a promising way forward. Such approaches combine the interpretability and rigor of physics with the flexibility and computational efficiency of machine learning. They deliver models that are fast, accurate, and explainable, without the need for huge datasets or resource-intensive training. This opens new research opportunities for accelerating innovation in energy technologies, from long-term system planning to real-time operation.

The talk will present examples of hybrid models developed for heat pumps and thermal energy storage, and their use for decision-making such as optimal real-time control. These results demonstrate how hybrid models can achieve speedups of up to two orders of magnitude compared with traditional approaches, while enabling more efficient and informed decision-making.

In this talk, we will discuss how hybrid modeling can become a cornerstone of model-driven energy system innovation. By bridging physics and data in complementary ways, it can provide the trustworthy, efficient, and scalable tools required to accelerate the deployment of clean energy solutions.