ECE 598: Computational Power Systems

Term: Winter 2025
Credit Hours: 3 credits
Time: Fridays 10:30-13:30
Format : Lecture (75 min) + Break + Tutorial (75 min)
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Course Description

The growing digitization of power systems and the rapid integration of renewable energy resources call for new computational algorithms to support power system operations and electricity markets. In this course, students will learn the core computational problems in power systems and modern algorithms to solve those problems, while managing the trade-offs between performance, speed and data requirements.

In the first part of the course, students will familiarize themselves with optimization problems in power systems, including economic dispatch and market clearing for transmission grids, as well as voltage control and peer-to-peer markets for distribution grids. They will also learn how machine learning (ML) aids in solving these optimization problems. In the second part, the focus will be on decentralized/distributed decision-making in high-voltage and distribution grids, and how agents can autonomously solve dispatch, control, and learning problems using decentralized/distributed algorithms, such as dual decomposition, ADMM, and their variants. In the third part, students will acquire prescriptive analytics skills: it will introduce algorithms for decision-focused learning in the context of renewable power forecasting and other relevant analytical tasks. Students will work on final projects (to be agreed upon with the instructor) and present the results to their peers. Possible project topics include:

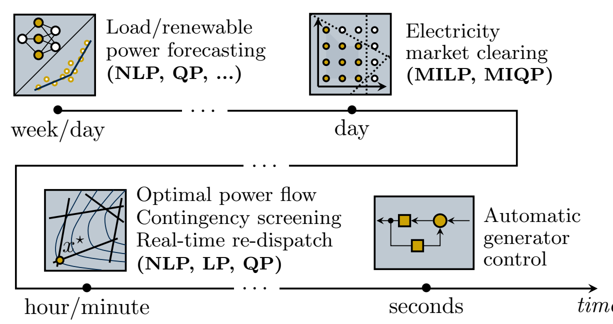

Figure 1: Computational power systems timeline

- Decentralized electricity market designs
- Carbon-constrained electric power dispatch and pricing
- Optimization algorithms for voltage control in distribution grids
- Power grid coordination with adjacent infrastructures (e.g., with data centers)

Each weekly session will consist of a lecture and a follow-up tutorial on the lecture materials.

Tentative Topics

1. Introduction to Modern Power System Optimization
   - Optimization for operational planning of power systems
   - Optimization for wholesale and local electricity markets
   - Optimization for distribution grid control
   - Selected machine learning applications in power systems
2. Decentralized/Distributed Optimization of Power Systems
   - Introduction to decentralized/distributed optimization algorithms
   - Distributed algorithms for voltage control in distribution grids
   - Decentralized optimization of wholesale electricity markets
   - Distributed optimization of local electricity markets
   - Distributed learning for renewable power forecasting
3. Prescriptive Analytics for Power Systems
   - Decision value of renewable power forecast (predict-then-optimize)
   - Decision-focused renewable power forecasting (smart predict-then-optimize)
   - End-to-end learning with custom gradient-based algorithms
   - Verification of machine learning models applied to power systems

Prerequisites

Students will follow the course more seamlessly having experience with power systems modeling, convex optimization (linear programming, duality theory), basic concepts of data science (for example, probability, sampling, regression), and have a good command of programming languages (e.g., Julia or Python). Formally, for this graduate-level course, the students are expected to take (EECS 463) and (IOE 310 or EECS 536 or IOE 510 or Math 561 or OMS 518) and (Math 425 or IOE 265 or EECS 301) before registering for this course, or get permission of the instructor.

Evaluation

The final grade is made of: (*i*) five homework assignments ($\approx$ biweekly, 40%), (*ii*) paper review (15%), (*iii*) final project (25%), (*iv*) participation (quizzes, notes, piazza, course evaluation, 20%).

Final Project Information

Before starting the project, your proposal should be approved by the instructor. The group work with up to 3 students is encouraged; we ask to report individual contributions in the separate section of the report. The deliverables include a 6-page report and in-class presentation.

Course Policies

Homework Assignments: Homework will be released on Friday, due two weeks after (i.e., the next, next Friday). You are welcome to discuss homework with others, but the answers must be your own. You have to list people you have talked to about each problem at the top of the report.

It makes it so comfortable to read your assignment reports if they are typed using LaTeX. Handwritten and scanned .pdf versions are also allowed and will not result in grading differences.

Requests for deadline extensions must be made in advance, to allow the instructor to correctly time the release of solutions and summaries. Failure to do so will result in a 50% deduction of the assignment points. You are welcome to request for at most 2 extensions up to 5 days in total.

The regrading request needs to be submitted within 2 weeks after the grade is released.

Course Participation: We aim to build a community around computational power systems, and thus offer you an opportunity to earn 20% of the final grade via active participation in the form of:

In-class quiz (10%): In the beginning of each class, will do a quiz to recap the materials from the previous lectures, and we will also do a quiz in the end of the class to cement the knowledge.

Lecture notes (5%): To enable the continuation of computational power systems knowledge across generations of students, we offer an opportunity to earn 5% of the final grade by sharing your lecture notes. We will set up a spreadsheet where you can sign up to scribe for at least five lectures. The notes are encouraged to be typed using LaTeX in the template provided at the beginning of the course, and you are welcome to work in groups of up to two people. The lecture recordings will be posted on Canvas to assist with this effort. Here are examples of lecture notes from other classes: Example 1, Example 2, Example 3.

Piazza (4%): To build a strong community, you will earn up to 4% of the final grade from active participation on Piazza. Typical engagement with Piazza would involve posting and responding to questions related to homework and final projects, sharing and discussing recent news from the power systems industry, and discussing academic work relevant to the course.

Course evaluation (1%): Please help us to improve the course by submitting mid-term and final course evaluations; each evaluation is worth 0.5% points.

Requirement relief: There is one drop-off of the lowest grade of all homework assignments. In other words, the 4 highest scored assignments will be counted for the final grade. There is also a drop-off of the lowest grades of 3 in-class quiz problems.

Honor code: Hopefully, we will never get to it, but any honor code violation will result in an additional loss of 50% points (beyond the findings/recommendations of the honor council).

Literature

1. Chatzivasileiadis, Spyros. "Lecture notes on optimal power flow (OPF)." arXiv preprint arXiv:1811.00943 (2018).

2. Molzahn, Daniel K., et al. "A survey of distributed optimization and control algorithms for electric power systems." IEEE Transactions on Smart Grid 8.6 (2017): 2941-2962.

3. Conejo, Antonio J., Miguel Carrión, and Juan M. Morales. Decision making under uncertainty in electricity markets. Vol. 1. New York: Springer, 2010.

4. Ben-Tal, Aharon, Laurent El Ghaoui, and Arkadi Nemirovski. Robust optimization. Vol. 28. Princeton university press, 2009.

5. Boyd, Stephen P., and Lieven Vandenberghe. Convex optimization. Cambridge university press, 2004.

6. Boyd, Stephen, et al. "Distributed optimization and statistical learning via the alternating direction method of multipliers." Foundations and Trends® in Machine learning 3.1 (2011): 1-122.

7. Scutari, Gesualdo, et al. "Convex optimization, game theory, and variational inequality theory." IEEE Signal Processing Magazine 27.3 (2010): 35-49.

8. Mandi, Jayanta, et al. "Decision-focused learning: Foundations, state of the art, benchmark and future opportunities." arXiv preprint arXiv:2307.13565 (2023).