ECE 598: Computational Power Systems

Term: Winter 2025
Credit Hours: 3 credits
Time: M/W 10:30-12:00
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Course Description

The growing digitization of power systems, the rapid penetration of distributed energy resources, and the decentralization of decision-making call for new computational algorithms to support power system operations and electricity markets. This course provides an overview of computational problems in power systems and introduces a range of computational algorithms to solve them, while recognizing the trade-offs between performance, speed, and data requirements.

The course is arranged in three parts. The first part overviews optimization problems in power systems, ranging from economic dispatch and market clearing in high-voltage grids to distributed algorithms for voltage control and peer-to-peer markets in distribution grids. This part also overviews how machine learning (ML) aids these optimization problems. The second part focuses on decentralized/distributed decision-making in high-voltage and distribution grids, and how agents can solve dispatch, control, and learning problems autonomously using decentralized/distributed algorithms, such as dual decomposition, ADMM, and their variants. The third part is devoted to prescriptive analytics for power systems and introduces the algorithms for decision-focused learning in the context of renewable power forecasting and other relevant analytic tasks. The course participants will work on final projects to be presented before, and evaluated by, their peers. Possible project topics include:

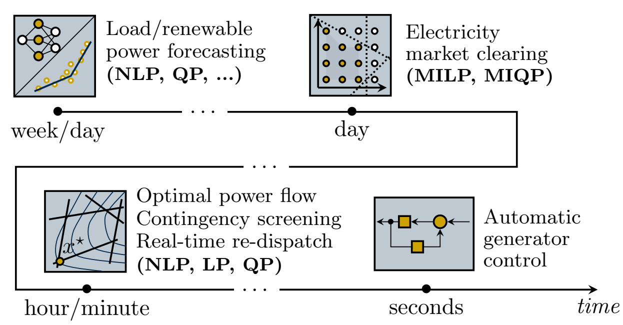

Figure 1: Computational power systems timeline

- Pricing electricity under uncertainty
- Algorithms for peer-to-peer electricity trading
- Carbon-constrained electric power dispatch and pricing
- Leveraging electrical vehicles for voltage control in distribution grids

- Power grid coordination with adjacent infrastructures (e.g., with data centers)

Tentative Topics

1. Introduction to Modern Power System Optimization
   - Optimization for operational planning of power systems
   - Optimization for wholesale and local electricity markets
   - Decision-making under uncertainty in power systems
   - Selected machine learning applications in power systems
2. Decentralized/Distributed Optimization of Power Systems
   - Introduction to decentralized/distributed optimization algorithms
   - Fast ADMM solver for distribution grids under uncertainty
   - Decentralized optimization of wholesale electricity markets
   - Distributed optimization of peer-to-peer 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

The project is on a topic of the student choice, to be agreed upon with the instructor. The group work is encouraged with up to 3 students in each group; students are expected to report individual contributions in the separate section of the report. The requirements involve:

- Submit a project proposal, due on TBA.
- Submit a presentation, due on TBA.
- Submit an 6-page report due on TBA.

Course Policies

Homework Assignments: Homework will be released on Friday, due two weeks after (i.e., the next, next Friday). Students can discuss homework assignments with other students, but their answers must be their own. Students should list people they have talked to about each problem at the top of each report.

All assignments are encouraged to be typed using LaTeX and submit the .pdf file electronically by 11:59 PM Eastern Standard Time on the assigned due date. Hand-written and scanned .pdf versions are allowed, which will not result in grading differences.

Requests for assignment due date extensions must be made in advance. Failure to do so will result in 50% off of the assignment points; Each person can make up to 2 extensions at most, and up to 5 days in total.

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

Course Participation: Your course participation will constitute 20% of the final grade.

In-class quiz (7.5%): We will use iClicker for in-class quizzes.

Lecture notes (7.5%): Your lecture notes will count towards the final grade. To earn the maximum score, student should sign up to scribe at least 5 lectures. The notes are encouraged to be typed using LaTeX in the template provided at the beginning of the course; students using LaTeX are allowed to work in groups of up to 3 people. The lecture recording will be posted on canvas to help this effort. Example of lecture notes from other classes: Example 1, Example 2, Example 3.

Piazza (4%): Piazza will be used for discussions among students. Participation in Piazza conversations will be a significant part of the final score. Please feel free to post technical and conceptional questions, but after screening already posted questions.

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: 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).