EC 500 Control of Sustainable Power Systems
Spring 2025

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Course description: This course focuses on computational methods for control of modern power systems, with particular emphasis on renewable generation and system sustainability. To build background, the course covers basics of linear systems, feedback control, and convex optimization. With this groundwork, the course explores methods that are currently utilized to optimize generation in today's operation of power grids; these methods include the economic dispatch, unit commitment, DC optimal power flow (OPF), and AC OPF at the power transmission level. The course then covers primary frequency control methods, secondary control methods, and automatic generation control, along with an analysis of system stability. The contribution of inverter-based resources to stability and grid-forming setups under massive renewable generation integration is discussed. At the power distribution level, the course addresses formulations and solution methods for demand response problems and the AC OPF, with an emphasis on modern distribution grids with distributed energy resources (DERs). The course emphasizes the understanding of the convergence and optimality properties of optimization algorithms used to solve demand response and OPF tasks. Finally, the course introduces advanced algorithms for real-time demand response and AC OPF, focusing on computational methods for the reliable integration of DERs and decarbonization of the power grid.

Lectures: Monday and Wednesday, 10:10 AM - 11:55 AM, 640 Commonwealth Ave COM 215.

Lectures will be in-person. Most of the lectures will alternate between blackboard and slides; additional electronic material may be provided to complement the discussion. Reading assignments will be provided on a lecture-by-lecture basis.

Office hours: Mondays, 1:00 PM - 2:00PM. Additional office hours on Wednesdays, by appointment.

Prerequisites: No strict prerequisites. However, prior attendance of ENG EC 402, ENG 417, and ENG EC 524 is encouraged.

Undergraduate Prerequisites: ENG EK 103. Students are expected to be have a high level of comfort with algebra and mathematical derivations. Familiarity with matrices at the level of ENG EC 402, or consent of instructor.

Computing Tools: MATLAB or Python will be required for some homework problems and for the projects. Students may need to use optimization packages (such as CVX and YALMIP) and electric power distribution system simulators (such as MATPOWER and OpenDSS) for their projects.

Textbook: The course will cover material from a diverse set of sources. Some of the concepts can be found in the following books:

- S. H. Low, *Power Systems Analysis - A Mathematical approach*, 2024.
- S. Boyd, L. Vandenberghe, *Convex Optimization*, Cambridge University Press.

An electronic version of these books is available on the authors' websites.

The instructor will provide additional material and scientific papers on the subjects covered in the course. The material will be uploaded on Blackboard.

Course goals: Students will:

- Familiarize themselves with the traditional operation of power systems and understand the computational challenges and solutions for reliably integrating DERs at both transmission and distribution levels.
- Develop a sound and versatile toolkit to address problems related to the design and analysis of control methods and algorithms in modern power systems.
- Gain a deep understanding of optimization algorithms, including their convergence and optimality properties in the context of power systems operations.
- Acquire problem-solving skills ranging from foundational concepts to the scientific frontier in modern power and energy systems.

More broadly, the aim is to provide students with a strong foundational background, enabling them to pursue systems-centered or energy-centered PhD paths or explore future opportunities in the power engineering and control systems industries.

Learning outcomes: After taking this course, students will:

- Be able to recognize and formulate optimization and control problems in power systems.
- Understand solution methods for economic dispatch and OPF in transmission systems.
- Understand solution methods for OPF and demand response problems in distribution systems, which emphasis on an optimal and reliable integration of DERs.
- Understand classes of optimization problems in power systems, and the properties of iterative optimization algorithms.
- Be able to design and analyze algorithms for real-time optimization of DERs.
- Understand frequency control and be able to carry out a small-signal analysis.
- Be able to simulate optimization algorithms, test algorithms on power systems case studies, explain results to peers.

Grading: The grade will be based on the following criteria:
- Homework: 30%
- Midterm: 30%
- Final project: 40%

No curving is implemented for the homework. For the Midterm, the finalized grade may be adjusted based on the distribution of the scores across the class. A different set of problems may be assigned to undergraduate students.

Final grades will be assigned according to the following scale:
A: 93 $\leq$ to 100; A-: 90 $\leq$ and $<$ 93;
B+: 87 $\leq$ and $<$ 90; B: 83 $\leq$ and $<$ 87; B-: 80 $\leq$ and $<$ 83
C+: 77 $\leq$ and $<$ 80; C: 73 $\leq$ and $<$ 77; C-: 70 $\leq$ and $<$ 73;
D+: 67 $\leq$ and $<$ 70; D: 63 $\leq$ and $<$ 67; D-: 60 $\leq$ and $<$ 63
F: $<$ 60.

Homework: Homework will be assigned approximately on a weekly basis, except for weeks where students will work on the project proposal, report, and presentation. A late homework is not accepted.

Midterm The Midterm will be in class, during the lecture time slot. Students can use the books, their lecture notes, and the material provided by the instructor in class. During the exam, the use of the Internet is not allowed. Students are not allowed to collaborate.

Project The project should be centered around one of the topics covered in the course. Successful projects apply the theory and methods covered in class to a particular problem in power systems. Students are encouraged to select a problem that is aligned with personal interests or current research efforts. The project should include an analytical part, as well as an experimental part. Projects solely focused on theory or on simulations might be accepted on a case-to-case basis.

Students will be asked to submit a project proposal. The final project will involve a report and a presentation.

Topics: The following topics will be tentatively covered (not necessarily in chronological order):

- Introduction and power systems modeling (2-3 lectures)
  - Power system infrastructure
  - Power flow equations and their solution
  - Conventional generation and distributed energy resources (DERs)
- Mathematical background (4-5 lectures)
  - Concepts of local and global minima
  - Convex sets and convex functions
  - Convex problems
  - Gradient-based optimization algorithms
  - Duality theory
  - Basics of Lyapunov stability for linear time-invariant dynamical systems
- Optimization and control of transmission systems (6-7 lectures)
  - Economic dispatch
  - Locational marginal prices
  - DC optimal power flow (OPF)
  - AC OPF and convex relaxation
  - Primary frequency control
  - Secondary control
  - Automatic generation control
  - Contribution of inverter-based DERs
- Optimization and control of distribution systems (6-7 lectures)
  - AC OPF
  - Multi-phase modeling
  - Multi-period optimization of energy storage systems
  - Demand response and the concept of aggregators
  - Volt/Var control
- Real-time optimization (2-3 lectures)
  - Online OPF methods
  - Online demand response methods
  - Performance analysis

Timeline:

- First homework assignment: January 29th, 2025.
- Expect weekly assignments (with some breaks).
- Midterm: March 24th, 2025.
- Project preliminary proposal: March 12th, 2025.
- Project proposal: April 2nd, 2025.
- Project report: Week of May 1st, 2025.

Collaboration Policy: For some homework assignments, the instructor will allow collaboration between students. However, students must:

- List the collaborators when submitting the homework solutions.
- Write all answers in their own words (i.e., students that collaborate cannot submit copies of the same answer).
- If the assignment involves coding, write their own code.
- If the assignment involves simulations, perform their own simulations and explain the results.

Source Policy: For homework assignments and final project, students can use books, their lecture notes, and the material provided by the instructor in class. Students can also use material from the Internet. However, the following conditions are strictly enforced:

- Students must list all the sources when submitting the homework solutions and the final project report.
- Students must specify which source was used and where in the solutions.
- If a source is not specified, students Students must be able to fully explain their answers or provide the source is asked. If students are not able to explain their answers or provide the source, there will be a penalization in the grade.
- Students must not use web-based help services, outside tutors, and generative AI.

If you are not sure whether something is permitted by the course policy, please ask the instructor.

Make-ups: There will be no make-up homework. If you have a legitimate excuse, such as illness documented by a doctor's note, then the scores of your other homework assignments will be weighted more highly to compensate for the missed homework. If you do not have a legitimate excuse, you will be given a grade of zero for the homework assignment. If you miss more than two homework assignments, the instructor will discuss a back-up plan for the remaining homework assigments.

In case of illness documented by a doctor's note, there will be a make-up midterm.

There will be no make-up project. Students will have plenty of time for the completion of the final project, and the submission deadline will be enforced strictly.

Incompletes: An incomplete grade will not be given to students who wish to improve their grade by taking the course in a subsequent semester. It may be given for medical reasons where a doctor's note is provided.

Academic misconduct: BU takes academic integrity very seriously. Academic misconduct is conduct by which students misrepresent their academic accomplishments, or impede other students' opportunities of being judged fairly for their academic work. Knowingly allowing others to represent your work as their own is as serious an offense as submitting another work as their own. More information on BU's Academic Conduct Code, with examples, may be found at http://www.bu.edu/academics/policies/academic-conduct-code

Accommodations: If you are a student with a disability or believe you might have a disability that requires accommodations, requests for accommodations must be made in a timely fashion to Disability & Access Services, 25 Buick St, Suite 300, Boston, MA 02215; 617-353-3658. Students seeking academic accommodations must submit appropriate medical documentation and comply with the established policies and procedures; see: http://www.bu.edu/disability/accommodations/