ECE 145: Modern Electric Power Systems

Schedule, Spring 2027 (tentative and subject to change)

Week of	Topics	Approximate textbook sections			
		Low	Kirtley	Glover et al.	Erickson & Maksimović
25-Jan	The grid as a machine: structure, scale, and balance	1.1.3-1.1.4	1	1.1-1.3	
	Phasors, complex power, and power factor	1.1, 1.3.1	2	2.1-2.3	
	HW0 (your grid) and HW1 out Mon 25-Jan				
1-Feb	Three-phase systems, symmetrical components, and per unit	1.2, 1.3.2-1.3.3, 3.5, 14.2.2	3, 4	2.5-2.7, 3.3, 9.1	
	Magnetics: transformers and synchronous machines *(possible guest)*	3.1-3.4	6, 9	2.8, 3.1-3.5, 12.2	
	HW0 due Mon 1-Feb	Observances: Lunar New Year, Sat 6-Feb			
8-Feb	Transmission lines: parameters, π model, and ratings; loads	2.1-2.2		4.1-4.2, 5.1-5.6, 12.8	
	Network matrices: Y_{bus} as a weighted graph Laplacian	4.1-4.3.3, 4.5, 4.6.1	1	2.4, 6.4	
	Optional visit: Blackstone Steam Plant, Fri 12-Feb (tentative)				
	HW1 due Mon 8-Feb; HW2 out	Observances: Ramadan begins about Mon 8-Feb; Ash Wednesday, Wed 10-Feb			
15-Feb	(Monday holiday: Presidents' Day)				
	The power flow equations and Newton-Raphson	4.3.4, 4.4	5	6.3-6.6	
22-Feb	DC power flow, PTDFs, and $N-1$ contingencies, with Sim lab I: operate a grid	4.6, 6.2.3		6.10, 6.12	
	Generators, the swing equation, and frequency control	6.3		12.1, 13.2-13.3	
	HW2 due Fri 26-Feb; HW3 out. Mon 22-Feb: add/drop deadline				
1-Mar	Faults, sequence networks, protection, and transient stability	16.4	4	8.3, 9-10, 11.8, 12.3-12.4	
	Economic dispatch, DC optimal power flow, and LMPs	6.1, 6.4.1-6.4.3		7.1-7.3	
	HW3 due Fri 5-Mar; HW4 out				
8-Mar	Midterm exam (written, closed book, in class; covers material through 3-Mar)				
	Electricity markets, AC optimal power flow, and energy burden	6.2, 9.1, 10.2		7.3-7.5	
	HW4 due Fri 12-Mar	Observances: Eid al-Fitr, Wed 10-Mar (or Tue 9-Mar)			
15-Mar	(Spring recess)	Observances: Nowruz, Sat 20-Mar			
22-Mar	Power electronics I: switches and DC-DC converters				1, 2, 4
	Power electronics II: solar PV, MPPT, and batteries			6.11	3, 6
	Project interest statement due Thu 25-Mar	Observances: Holi, Mon 22-Mar; Purim, Tue 23-Mar; Good Friday, Fri 26-Mar; Easter, Sun 28-Mar			
29-Mar	Power electronics III: rectifiers, harmonics, and power quality				20, 21
	Power electronics IV: inverters and PWM				6, 21
	Midterm revisions due Mon 29-Mar; HW5 out				
5-Apr	Power electronics V: grid-forming inverters, wind, HVDC, FACTS *(possible guest)*			5.7, 12.7	
	Distribution systems: LinDistFlow, DERs, EVs, and hosting capacity	5.2, 5.5, 7.2		15.1-15.5, 15.9	
	Project progress report due Fri 9-Apr				
12-Apr	Sensing and state estimation	7.1			
	Learning the grid from data: PCA, oscillations, and forecasting	7.3			
	HW5 due Fri 16-Apr; HW6 out	Observances: Vaisakhi, Wed 14-Apr; Ram Navami, Thu 15-Apr			
19-Apr	Machine learning for grid operations: learned optimal power flow				
	Sim lab II: agentic AI with power system tools				
		Observances: Ridván, Wed 21-Apr; Passover begins at sundown Wed 21-Apr			
26-Apr	Final project presentations (Mon 26-Apr)				
	Resilience, reliability, and the grid in the age of AI *(possible guest)*			15.7	
	HW6 due Tue 27-Apr	Observances: Passover through Thu 29-Apr; Orthodox Good Friday, Fri 30-Apr			
Finals	*Final project report due on the Final Deadline Group date* **TBD**				

Textbooks. Low: S. H. Low, *Power System Analysis* (sections). Kirtley: MIT 6.061 course notes (chapters). Glover et al.: Glover, Sarma, Overbye, and Birchfield, *Power System Analysis and Design*, 7th ed. (sections). Erickson & Maksimović: *Fundamentals of Power Electronics*, 3rd ed. (chapters). Weeks 11-13 draw on course notes and readings posted on Canvas. **Observances.** Class meets on these days; students who observe are excused, as the syllabus explains. Dates of lunar holidays may shift by a day.

Weekly learning goals

The learning goals below should be viewed as the key concepts you should grasp after each week, and also as a study guide before the midterm exam, and at the end of the semester. The applications in the second half of the semester tend to build on the concepts in the first half of the semester though, so it is still important to review those concepts throughout the semester.

Week 01, 01/25 - 01/29: The grid as a machine; phasors and complex power

- Describe the structure of the electric grid, from generation through transmission and distribution, and why supply must balance demand at every instant.
- Represent sinusoidal quantities in steady state as phasors, and compute complex, real, and reactive power and the power factor.

Week 02, 02/01 - 02/05: Three-phase systems, the per-unit system, transformers, and generators

- Analyze balanced three-phase circuits in wye and delta configurations using per-phase equivalents, and decompose unbalanced ones into symmetrical components.
- Model ideal and practical transformers, and convert between physical and per-unit quantities across voltage zones.
- Explain how a synchronous generator turns mechanical power into electrical power, and why it behaves like a PV bus.

Week 03, 02/08 - 02/12: Transmission lines, loads, and network matrices

- Derive the π-model of a transmission line from its series impedance and shunt admittance, and explain what limits the power a line can carry, including thermal and dynamic line ratings.
- Model loads as constant impedance, current, or power, and explain how many small loads aggregate into one.
- Construct the bus admittance matrix from the incidence matrix as a weighted graph Laplacian, and connect it to Kirchhoff's laws.

Week 04, 02/15 - 02/19: The power flow equations (Monday 02/15: Presidents' Day, no class)

- Write the power flow equations in polar form, and classify slack, PV, and PQ buses.
- Solve the power flow equations with the Newton-Raphson method, and interpret the Jacobian and quadratic convergence.

Week 05, 02/22 - 02/26: DC power flow, contingencies, and frequency control

- Derive the DC power flow approximation, state its assumptions, and recognize when it fails.
- Compute power transfer distribution factors (PTDFs), and use them to screen $N-1$ contingencies.
- In Sim lab I, operate a test grid: find the lines that limit it and the outages that would overload it.
- Derive the swing equation of a synchronous generator, and interpret the role of inertia.
- Explain primary (droop), secondary, and tertiary frequency control, and compute the frequency nadir and rate of change of frequency after a disturbance.

Week 06, 03/01 - 03/05: Faults, economic dispatch, and locational marginal prices

- Compute the currents of balanced and unbalanced faults with sequence networks, and describe how protection isolates them.
- Analyze transient stability with the equal-area criterion, and find how fast a fault must be cleared.
- Formulate and solve the economic dispatch problem, and interpret the system marginal price.
- Formulate the DC optimal power flow problem as an optimization program in JuMP.
- Derive locational marginal prices from the dual of the DC optimal power flow problem, and decompose them into energy and congestion components.

Week 07, 03/08 - 03/12: Midterm exam; electricity markets and AC optimal power flow

- **Midterm exam in class on Monday 03/08.**
- Describe how day-ahead and real-time electricity markets clear, and contrast regulated and restructured markets.
- Formulate the AC optimal power flow problem, and contrast relaxations and approximations of the power flow equations.
- Assess fairness in electricity pricing using the energy burden metric.

Spring recess, 03/15 - 03/19: No class.

Week 08, 03/22 - 03/26: Power electronics: DC-DC converters, solar, and batteries

- Analyze buck, boost, and buck-boost converters in steady state with volt-second and charge balance.
- Build averaged models of switching converters, and compare them with simulations of the switches themselves.
- Model how the current of a solar panel depends on its voltage, and design a converter and a maximum power point tracking algorithm that extract the most power from it.
- Describe how batteries connect to the grid through bidirectional converters.

Week 09, 03/29 - 04/02: Power electronics: rectifiers, harmonics, and inverters

- Analyze diode rectifiers, and compute the harmonics, total harmonic distortion, and power factor of nonsinusoidal currents.
- Explain how harmonics from data centers, electric vehicle chargers, and inverters spread through a network, and why triplen harmonics add up in the neutral.
- Analyze single-phase and three-phase inverters, and explain how pulse width modulation synthesizes a sinusoidal voltage.

Week 10, 04/05 - 04/09: Inverter-based resources and distribution systems

- Contrast grid-following and grid-forming inverter control, and describe the challenges of operating grids with low inertia.
- Describe how wind turbines, HVDC links, and FACTS devices connect to and control the grid.
- Model radial distribution feeders with the LinDistFlow approximation.
- Analyze voltage regulation and hosting capacity with rooftop solar, storage, and electric vehicles.

Week 11, 04/12 - 04/16: Sensing, state estimation, and learning the grid from data

- Compare SCADA, phasor measurement units, and smart meters as sources of grid data.
- Estimate the state of a power network with weighted least squares, and detect bad data.
- Find the low dimensional structure in phasor measurement unit data with principal component analysis, and use it to detect events and forced oscillations.
- Reconstruct power flow sensitivities from measurements, without a model of the network.

- Forecast load from real balancing authority data, and evaluate forecasts against simple baselines.

Week 12, 04/19 - 04/23: Machine learning and AI for grid operations

- Train learned surrogates for optimal power flow, and evaluate them for feasibility as well as accuracy.
- Add physical constraints to learned models, and evaluate when grid operators can rely on them.
- In Sim lab II, use an AI agent connected to power system tools to answer an operations question, and check every number it reports against the laws of physics.

Week 13, 04/26 - 04/30: Resilience, reliability, and the grid in the age of AI

- Analyze extreme events through case studies, such as the 2021 Texas freeze and the 2025 Iberian blackout.
- Assess how load growth from AI data centers affects grid planning and electricity prices.
- Revisit the predictions you made in Homework 0.
- **Project presentations on Monday 04/26.**

Reading Period, 04/29 - 05/05: No class and no new material.

Final Examination Period, 05/06 - 05/15: **Final project report due TBD.**