Energy Systems and Control

October 11, 2013

Primary Goal: Provide an introduction to emerging smart energy systems and the associated fundamental concepts in control systems theory.

Short Description:

Introduction to energy system management and the underlying control system tools. Applications of interest include batteries, electric vehicles, renewable energy, power systems, and smart buildings/homes. Technical tools include system modeling, state-space representations, stability, parameter identification, state observers, feedback control, and optimization.

Expanded Description:

Emergent energy systems, such as batteries and smart grids, provide motivating examples of critically important dynamical systems which must be carefully analyzed, designed, monitored, and managed. When formulated as a dynamical system, each of these aforementioned tasks map to a fundamental problem in systems and control theory. Systems and control theory is an interdisciplinary branch of engineering which studies the behavior and management of dynamical systems. As such, this course introduces systems and controls tools within the context of energy systems. The course is oriented towards students with interests in energy and strong undergraduate backgrounds in mathematics, physics, and engineering.

The course begins with an overview of energy systems in various infrastructures, e.g. transportation, power systems, and the built-environment. The first unit utilizes battery energy storage as a motivator for studying state-space models, parameter identification, and state observers (i.e. Kalman filters). In the second unit we study electrified transportation and drive cycle models as a motivator for system identification, stochastic modeling, and optimal control. The third unit introduces power systems and renewable energy as a motivator for directed graph models and predictive control. The fourth unit covers demand response of large populations of flexible loads. This motivates continuum modeling via partial differential equations and reference tracking via feedback control. The course also includes a project in which students must study an energy system of their own interest, from a systems and controls perspective.

Course Format/Time: 3 hours of lecture per week.

Prerequisites: Graduate standing in engineering or physical science, or consent of instructor.

Assessment & Grading:

Homework:	30%	5 or 6 two-week assignments
Midterm:	20%	In-class exam
Project:	30%	Proposal (5%), In-class presentation (10%), and final report (15%)
Final:	20%	In-class exam

Week-by-Week Lecture Topics

Wk	Description	Reading
1	Overview of energy systems in transportation & power infrastructures	[1]
2	Energy storage : batts, FCs, UCs, CAES, flywheels	[M §8.6, 9.3]
3	State-space models. Lyapunov stability.	[I&S §2.2, 3.4]
4	Parameter identification. Case study on batteries.	[I&S §4, R&W §7.2]
5	Observability. State estimation theory.	[S, §4.5]
6	Kalman filters. Case study on batteries	[R&W §7.2], [2]
7	Electric mobility: HEVs, PEVs, autonomous & shared vehicles	[3]
8	Drive cycle modeling	[4]
9	Optimal energy management: DP, MPC, ECMS	[5]
10	Overview of power systems, renewable energy: solar, wind, hydro	[M §1], [6, 7]
11	Demand response	[M §9.4]
12	Modeling large populations with PDEs: TCLs & PEVs	[8]
13	Balancing renewables via feedback control	[9, 10]
14	Smart buildings & homes	[11, 12]
15	Final project presentations	

Recommended Textbook Material:

Note: There is no required textbook.

[M] G. M. Masters, Renewable and Efficient Electric Power Systems, John Wiley & Sons, 2013

[R&W] C. D. Rahn and C. Y. Wang, Battery Systems Engineering, John Wiley & Sons, 2013

[S] R. F. Stengel, Optimal Control and Estimation, Dover Publications, 1994

[P&S] P. A. Ioannou and J. Sun, Robust Adaptive Control, Dover Publications, 2012

References

[1] A. N. Annaswamy, M. Amin, C. L. DeMarco, and T. Samad, "IEEE Vision for Smart Grid Controls: 2030 and Beyond," IEEE, Tech. Rep., 2013.

[2] S. J. Moura and H. Perez, "Extracting the Full Potential of Batteries: Electrochemistry and Controls," *ASME Dynamic Systems and Control Magazine, in review*, 2014.

[3] A. M. Phillips, R. A. McGee, J. G. Kristinsson, and H. Yu, "Smart, Connected, and Electric: The Future of the Automobile," *ASME Dynamic Systems and Control Magazine*, pp. S4–S9, 2013.

[4] C. Sun, X. Hu, S. J. Moura, and F. Sun, “Comparison of Velocity Forecasting Strategies for Predictive Control in HEVs,” in *Proceedings of the 2014 American Control Conference*, 2014.

[5] G. Rizzoni and H. Peng, “Hybrid and Electrified Vehicles: The Role of Dynamics and Control,” *ASME Dynamic Systems and Control Magazine*, pp. S10–S17, 2013.

[6] J. P. Aho, A. D. Buckspan, F. M. Dunne, and L. Y. Pao, “Controlling Wind Energy,” *ASME Dynamic Systems and Control Magazine*, pp. S4–S12, 2013.

[7] C. Vermillion and L. Fagiano, “Electricity in the Air: Tethered Wind Energy Systems,” *ASME Dynamic Systems and Control Magazine*, pp. S14–S21, 2013.

[8] S. J. Moura, V. Ruiz, and J. Bendsten, “Modeling heterogeneous populations of thermostatically controlled loads using diffusion-advection pdes,” in *Proceedings of the ASME Dynamic Systems and Control Conference*, 2013.

[9] G. Strbac, “Demand side management: Benefits and challenges,” *Energy Policy*, vol. 36, no. 12, pp. 4419–4426, 2008.

[10] D. Callaway and I. Hiskens, “Achieving controllability of electric loads,” *Proceedings of the IEEE*, vol. 99, no. 1, pp. 184 –199, jan. 2011.

[11] S. Bashash, S. J. Moura, and H. K. Fathy, “On the aggregate grid load imposed by battery health-conscious charging of plug-in hybrid electric vehicles,” *Journal of Power Sources*, vol. 196, no. 20, pp. 8747 – 8754, 2011.

[12] Y. Ma, A. Kelman, A. Daly, and F. Borrelli, “Predictive control for energy efficient buildings with thermal storage: Modeling, stimulation, and experiments,” *Control Systems, IEEE*, vol. 32, no. 1, pp. 44–64, 2012.