EE527

Net-Centric Power-System Control

Fall 2013

Power Initiative Course Developed by

Edmond Jonckheere

Ming Hsieh Department of Electrical Engineering
University of Southern California
3740 McClintock Avenue, Room EEB306
Los Angeles, California 90089-2653
Tel: (213) 740-4457
Fax: (213) 821-1109
e-mail: jonckhee@usc.edu
web page: http://eudoxus2.usc.edu

Rationale

This course was developed in 2010 in response to the "smart grid" government-initiated program. The *Southern California Edison* and the *Los Angeles Department of Water and Power* were also instrumental in setting up this course, as both organizations perceived the need for a "crash program" to train a new breed of power engineers able to cope with the energy problems the country is likely to face in a not-so-distant future. Among those problems, one will retain fluctuation due to renewables, reactive power management, line overloading, and voltage stability.

This program came at a time when there is more and more concern about the information grid vulnerability to attacks and its potential impact on the power grid, as the power grid and the information grid are more and more intertwined.

This program is also concomitant with a revival of control in the wake of *Networked Control* and *Network Control*. The two concepts should not be confused: *Networked Control* refers to large-scale distributed control systems borrowing the information infrastructure to transmit sensing/actuating signals through unreliable channels. *Network Control* refers to the control of networks to have them work properly, for example, control of the network to avoid congestion, Random Early Detection (RED). "Smart" control of the power grid using Phasor Measurement Units (PMU's) would qualify as *Networked Control.*

This new course is, therefore, designed at the crossroad between the power grid, the information network, and their control. It will be taught in a way that should be of interest to the power grid, the computer networking, and the control communities. This symbiotic approach can certainly be justified on the ground that software vulnerabilities have been shown to have the potential to create blackouts, but next to this, there is the more compelling reason that congestion control techniques initially developed for information grid are in fact applicable to the line overload in the power grid.

Power grid versus information grid topology

There has been a tremendous amount of activity on the topology of the information grid. Such concepts as Scale-Free networks and Small-World networks have dominated the Internet publication arena over the past 15 years. However, this line of research has shown signals that, on the one hand, it is running out of steam and, and on the other hand, that it might not have captured the topological features of real power, communication, transportation, and other networks. This has created a still on-going revolution in the field, trading the old concept of Scale-Free networks for negatively curved Gromov hyperbolic grids, a revolution that is currently pervading the power grid. The universal acceptance of the concept of Gromov hyperbolic networks stems from the fact that, in the information grid, it is closely related to congestion and queue overflow and, in the power grid, it is related to line overloading.

Power grid versus information grid security

Among the aspects making the power grid “smart” is the massive deployment of Phase Measurement Units (PMU’s), which provide the sensing information that reflects the state of “health” of the grid. Unfortunately, sending the PMU’s across the grid via classical information technology for possible (centralized) control action makes the grid vulnerable to attacks, especially false data injection. In particular, in this course, we will focus on the recent *stealthy deception attack,* against which no protection has yet been found.

Power grid stability and control

Recent activities have focused on the impact of the topology of the network on voltage stability, especially in the wake of distributed renewables (photovoltaic cells (PVC’s) and wind farms). In particular the thyristor inverters of PVC’s that have the potential to inject reactive power that might contribute to stability, if managed properly.

Spirit of this course

All of the topics mentioned above are clearly calling for a “multidisciplinary course.” So, this course will be made of relevance to control, computer engineering, and power students.

Three parts of course

Part 1 (“Power Network”)

The first part of the course will be taught from the “networking” point of view. It is heavily graph oriented. It will proceed from graph topology, and then will develop a concept of “traffic” applicable to both the power and information grids. Both grids are driven by consumers’ demands, which can be formulated in terms of the “traffic” that has to flow from “sources” (power generating stations, transmitters, resp.) to “destinations” (distributions, receivers, resp.) without creating “congestion” (line overload, packet drops, resp.).

Part 2 (“Security”)

This part deals with State Estimators (SE’s) and Phasor Measurement Units (PMU’s). For economic reasons, both SE’s and PMU’s will be operating concurrently in the smart grid, while sharing the risk of data tampering, hence sending wrong state information, with the potential of prompting the operator to respond in a way to create, in the worst case scenario, voltage collapse.

Part 3 (“Control”)

Part 2 is centralized around the concept of reactive power flow and voltage stability, which should be maintained despite fluctuation in the generation and the demand. This part is heavily “control oriented.” Fundamentally, it deals with stability of large-scale interconnected systems.

Format of course

Instructor

Dr. E. A. Jonckheere
EEB 306
(213) 740-4457
jonckhee@usc.edu

Meetings

Tuesday-Thursday, 5:00-6:20 pm, in RTH105 (available on DEN)

Office Hours

Tuesday & Thursday, 1:00-3:00 pm

Teaching Assistant:

TBA

Discussion Sessions

TBA

Prerequisite:

Basic linear feedback control (EE482); good working knowledge of linear algebra (EE441); Linear System Theory (EE585) is not a “must,” but is desirable as a “recommended preparation.”

Software, Matlab, etc.

Familiarity with Matlab will be assumed. In the course of the semester, MATPOWER will be reviewed and students will be required to become familiar with it and utilize it in homework assignments.

Course grading:

For this kind of research-oriented class, it is difficult to have traditional "sit-down" exams. The course grading will be based on homework, meant to be critical readings of specialized papers and research oriented exercises, a midterm project (due mid semester), and a final project (due end of semester):

Homework	30%
Midterm-project (due mid semester)	20%
Final project (due end of semester)	50%
Total	100%

Textbook:

It is difficult to find a textbook that covers all that has to be covered, especially since this proposed class deals with a topic that has only very recently taken shape. Nevertheless a text that comes close to the spirit of this proposed class is

- Romeo Ortega, Antonio Loria, Per Johan Nicklasson, and Hebertt Sira-Ramirez, Passivity Based Control of Euler-Lagrange Systems, Springer, 1998. ISBN: 1-85233-016-3. (This is a very good book on physically motivated Lagrangian control, especially relevant to Weeks 11-14.)

To compensate for the lack of formal textbook, the instructor will provide students with lecture notes, compiled last years, and covering just about the whole class.

Besides, the instructor will provide students with notes posted on the blackboard. For example:

1. Areeyata Sripetch and Poompat Saengudomlert, Topology Design of Optical Networks Based on Existing Power Grids, CNSR '07: Proceedings of the Fifth Annual Conference on Communication Networks and Services Research, 2007, ISBN 0-7695-2835-X, pages 35—40, DOI: http://dx.doi.org/10.1109/CNSR.2007.66, IEEE Computer Society, Washington, DC, USA.

2. J. A. Hall, Strategic environmental research and development program statement of need for FY08; Sustainable infrastructure (SI) new start; Scalable power grids that facilitate the use of renewable energy technologies, November 2006, Department of Defense, SON Number SISON-09-4, http://www.serdp.org/funding/.

3. Author withheld, Generating random topology power grids, https://wiki.iti.uiuc.edu/pub/Main/ZhifangWang/Hicss41_RandTopo_Wang_v2.pdf.

4. David L. Pepyne, Topology and cascading line outages in power grids, Journal of Systems Science and Systems Engineering, volume 16, number 2, June 2007, pages 202-221, DOI 10.1007/s11518-007-5044-8.

5. Eric J. Lerner, What's wrong with the electric grid? The Industrial Physicist, volume 9, Pages 8-13, October-November 2003.

6. P. Crucitti and V. Latora and M. Marchiori, A topological analysis of the Italian electric power grid, Physica A, volume 338, pages 92-97, 2004.

A. Fettweis, In Memoriam, Vitold Belevitch, IEEE Transactions on Circuits and Systems, Volume 47, pages 613-614, May, 2000.

7. T. Kottos and U. Smilansky, Quantum graphs: A simple model for chaotic scattering, J. Phys. A: Math and General, volume 36, page 3501, number 4, 2003.

8. P. Kuchment}, Graph models of wave propagation in thin structures, Waves in Random Media}, volume 12, year 2002, number 4, pages R1-R24.

9. G. L. Doorman and T. Holtedahl and H. S. Woldstad, Large scale power exchange in the greater Mekong subregion, International Conference on Electric Supply Industry in Transition: Issues and Prospects for Asia, Thailand, year 2004, January 14-16.

10. E.A. Jonckheere, Lagrangian theory of large scale systems, (invited paper), European Conference on Circuit Theory and Design, The Hague, the Netherlands, August 25-28, 1981, pp.626-629.

Time table

	FIRST PART: GRAPH THEORY OF TRANSMISSION NETWORK
August 2013	The concept of network. Information network, sensor networks, telephone network, power grid, bus model, transportation network, percolation network, quantum networks. The concepts of “flow” and “commodity;” multi-commodity flow, etc.
August 2013	Introduction to the power grid elements: generation, transmission, distribution. The deregulation issue and large-scale power transmission. The concept of “renewables” (wind farms, photo-voltaic cells).
September 2013	Classical (non-topological) graph topology. Degree distribution,

	Scale-Free graphs, Small-World graph model of power grid. Adjacency matrix, graph Laplacian. Topographical versus electrical connectivity.
September 2013	Resistive networks, Laplacian, effective resistance.
September 2013	Review of some electrodynamics (depending on students' background): Tellegen's theorem; complex power, active power, and reactive power. Lagrange-Hamilton formulation of circuits. Variational interpretation of active and reactive power.
September 2013	Power flow equations. Solving nonlinear power flow equations using Newton-Raphson iteration. Linear DC power flow models. Virtual resistive grids.
October 2013	Riemannian geometry of graphs. Approximation of a graph by a Riemannian manifold. Graph curvature, concept of Gromov hyperbolic graphs. Curvature of resistive networks. Concept of graph inertia.
October 2013	Line overload in power grid and its metaphoric congestion in information grid. Line overload in power grid will be shown to be more likely to happen if the grid is Gromov hyperbolic. Overloaded lines will be identified as those of low graph inertia.
	SECOND PART: STATE ESTIMATOR, PMU MEASUREMENTS AND SECURITY
October 2013	State Estimators (SE's) and large scale synchronous Phasor Measurement Units (PMU's) deployment. Time stamp by Global Positioning System (GPS). Networked PMU's.
October 2013	Detection of false data injection by structure learning of grid graph using Conditional Covariance Test (CCT). Application of structure learning to detect stealthy deception attack.
	THIRD PART: VOLTAGE STABILITY
November 2013	Nonlinear loads, load aggregation, the static-dynamic gap, describing function models.
November 2013	Review of control. Feedback and feedforward control. Closed-loop stability, Nyquist plot, Callier-Desoer criterion for stability of interconnected systems.
November-December 2013	Application of Modern Control Theory to voltage stability. Nonlinear uncertain loads viewed as diagonal perturbation wrapped around transmission network. Example of voltage collapse.