EPRI

GridEd

The Center for Grid Engineering Education

Grid-Ready Energy Analytics Training (GREAT) with Data
Digital Power Systems Course

This course is provided as an introductory course in digital power systems via The Center for Grid Engineering Education (GridEd) as a part of curriculum development under its U.S. DOE award from the Solar Energy Technology Office known as Grid-Ready Energy Analytics Training (GREAT) with Data as well as conceptualized and funded in part by Utilities comprising participants in an EPRI supplemental project "Educating a Digital Power Workforce to be GREAT with Data." More information about this initiative can be found on our GridEd website.

Instructional Strategy:

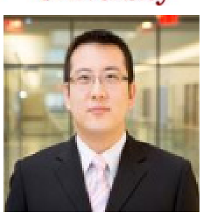
There are two instructional pathways:

A) **Free Open-Access Instructional Materials:** A sequence of recorded modular lectures, by multiple lecturers, following the syllabus of this course that is outlined below. Lecture videos, power point presentations, will be provided for free via EPRI's Training and Development Learning Management System. The material is intended as a self- taught effort. The materials are created under Creative Commons Copyright and any person or organization may use these materials for their own purposes. Contact Amy Feser, afeser@epri.com if you have trouble accessing.

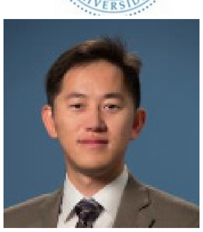
B) **Fee based Guidance Through Instructional Material:** Organizations seeking qualified instructional support to help guide participants through the material may approach Phil Markham, phmarkham@epri.com to schedule appropriate instructional support. *(This does not limit any organization from providing their own instructional support for students working through this material.)*

Meet the Instructors:

Stony Brook University



The project team consists of experts in power systems, cloud computing, machine learning, stochastic control, analytical modeling, energy-efficient computing, information inference, renewable energy integration, infrastructure resilience & security, statistical inference, game theory, and cyber security. Stony Brook University has experience with the complete lifecycle of technology development demonstrated by the industry's first "Net-zero Energy Data Center," which was a 2013 Computerworld Honors Laureate and includes a recipient of the 2012 IEEE Charles Hirsh Award "for the developing and implementing on Long Island, electric load forecasting methods and smart grid technologies". **Contact:** Zhenhua Liu, Zhenhua.liu@stonybrook.edu



Professor Yu serves as the funding co-chair for IEEE Power and Energy Society Big Data Applications in Power Distribution Network task force which will serve as a great venue for tech transfer. UC Riverside has a strategic Academic Partnership Program with Cloudera and is equipped with an Oracle Big Data Appliance, which provides hands-on data science training. UC Riverside serves east of Los Angeles known as the Inland Empire, which is more populous (4.5 million) than half of the U.S. More than 45 percent of UC Riverside undergraduates are underrepresented minority groups, and more than half are from disadvantaged backgrounds placing UC Riverside in a unique position to impact these groups. **Contact:** Nanpeng (Eric) Yu, nyu@ece.ucr.edu

The project team consists of experts in power systems, renewable energy integration, data science, deep learning, and robust optimization. UT's energy systems program is well known for its research and education efforts centered around the production, distribution, and use of electric energy. It also has a strong collaboration tradition with the electric power industry in emerging technology development and workforce training. UT's data science program has pioneered in establishing a comprehensive curriculum consisting of cutting-edge machine learning algorithms and their applications to various fields. The UT team brings valuable experience and innovative approaches to the design of new courses on data science and digital technologies for training the workforce on next-generation power systems. **Contact:** Hao Zhu, haozhu@utexas.edu

The institution, and PI Professor Liu, is a leader in cyber-physical system security of the power grid. Virginia Tech's research has collaborated with the industry to develop computational methods for vulnerability analysis and anomaly detection in the Supervisory Control and Data Acquisition (SCADA) system and substation automation environment. In addition to the many publications, Virginia Tech has accumulated extensive experience in developing and using testbeds for evaluation of cyber-physical system security. **Contact:** Chen-Ching Liu, ccliu@vt.edu

The project team consists of experts in power systems, renewable energy integration, data sciences, optimization and control, and cyber-physical systems. WSU's coveted power program offers a diverse curriculum that closely aligns with the need of the emerging power industry. At WSU, a rich collaboration between faculty members in power systems and computer science addresses emerging challenges for cybersecurity, big data, and information and communication technologies. WSU team has extensively contributed to educational material for training workforce on modern, and renewables-rich power systems operations. **Contact:** Anamika Dubey, **anamika.dubey@wsu.edu**

GRIDED

The Center for Grid Engineering Education

EPRI

Digital Power Course Syllabus

Section 1	Electric Power Network
1.1	• **Overview**
	o Overview of the power grid
	o Generation, transmission, distribution
	o Transmission network configuration
	o Distribution network configuration
	o Distributed energy resources – wind energy, solar PV and energy storage
	o Microgrids
	• **Power System Operation and Communications**
1.2	o Supervisory control and Data Acquisition (SCADA) System
	o Power system communications
	o Energy control centers - centralized transmission operation
	o Distribution operating centers – centralized distribution operation
	o Energy Management System (EMS)
	o Distribution Management System (DMS)
	o Distributed Energy Resources Management System (DERMS)
	o Microgrid control
	o Smart grid
1.3	• **Power Grid as an Electrical Network**
	o Laws of physics for electrical networks
	o Power flow in a steady state
	o Economic operation and dispatch
	o Control of frequency
	o Control of voltages
1.4	• **Power System Dynamics**
	o Small disturbance stability
	o Transient stability
	o Voltage stability
	o Power system faults and protection
	o Reliability, resilience, and security
	o Outages
	o N-k security
	o Reliability indices
	o Resilience under extreme events
	o Cyber-power system security
1.5	• **Reliability, Resilience and Security**
	o Outages
	o N-k security
	o Reliability indices
	o Resilience under extreme events
	o Cyber-power system security

Section 2	Electric Power Distribution System with Distributed Assets
2.1	• **Introduction to Electric Power Distribution Systems** o Introduction to distribution systems o Distribution systems components o Distribution management system o Feeder Voltage regulation o Outage management system, FLISR, Resilience
2.2	• **Load Characteristics** o Nature of load, and definitions o Load allocation o Voltage drop calculation
2.3	• **Distribution Transformers** o Transformer recap o Introduction to distribution transformers o Three-phase transformer connections o Other transformer connections
2.4	• **Line and Load Models** o ABCD parameter model for three-phase representation o ZIP load models o Voltage drop calculation
2.5	• **Distribution Power Flow** o Forward-backward sweep o Current injection power flow
2.6.1	• **Voltage Control Devices** o Step voltage regulators o Line drop compensation
2.6.2	• **Capacitor Bank Models and Voltage Control** o Voltage rise calculations
2.7	• **Distributed Energy Recourses** o Power distribution systems o Solar in world o Impacts of PV integration o Load conditions
2.8	• **Fault Analysis and Systems Protection** o Overcurrent protection basic principles o Overcurrent protection devices o Protection coordination
Section 3	**Digital Solution Techniques for Solving Network Equations**
3.1	• **Power Systems Representation**
3.2	• **Power Flow Analysis**
3.3	• **Power World Example Running**
3.4	• **Transient network analyzers**
3.5	• **PSCAD**

Section 4	Principles and Features of a Smart Grid Technology & Systems
4.1	• **What is a Smart Grid** • Part I • Part II
4.2	• **Renewable Generation**
4.3	• **Real Time Data Collection**
4.4	• **Integrated Data Communication**
4.5	• **Intelligent Decision Making**
4.6	• **Demand Response**
4.7	• **Economics and Market Operation**
4.8	• **Assignment** o Assignment Tutorial Part I o Assignment Tutorial Part II
Section 5	**Data Science**
5.1	• **Linear Regression and Robust Regression, Regularization** o Theory and application
5.2 - 5.3	• **Decision Trees, Random Forest and Boosting Trees (3 lectures) Hao and Yu** o Theory o Application
5.4	• **Support Vector Machines** o Theory and application
5.5	• **Deep Neural Network** o Feed-forward neural network o Theory and application o Highlight and list of full applications
5.6	• **Convolutional Neural Network** o Theory and application
5.7	• **Recurrent Neural Network** o Theory and application
5.8	• **Generative Model**
5.9	• **Cluster Analysis**
5.10	• **Dimensionality Reduction**
5.11	• **Introduction to Reinforcement Learning**
5.12	• **Markov Decision Process**
5.13	• **Dynamic Programming**
5.14	• **Monte Carlo Methods**
5.15	• **Temporal Difference**
5.16	• **Deep Q Learning**
5.17	• **Applications of Deep Reinforcement Learning**

GRIDED

The Center for Grid Engineering Education

EPRI

Section 6	Cyber Security of the Power Grid
6.1	• **Impact of Cyberattacks and Vulnerabilities**
	o Cyber-power system concept
	o Cyber vulnerabilities
	o Cyberattack modes
	o Cyber security concepts
	o Cyber security technologies
	o NERC CIP and compliance
6.2	• **Cyber-Power System Security**
	o Cyber system model
	o Power system model
	o Interactions between cyber and power systems
	o Abnormal steady state and dynamic behaviors caused by cyber attacks
	o Cyber-power system simulation environment
	o Intrusion scenarios
	o Quantifying the impact on the physical system
	o Vulnerability metrics
	o Reducing vulnerability
6.3	• **Cyber-Security of Transmission Systems**
	o SCADA security
	o Substations
	o Substation automation
	o Cyber security of substations
	o Anomaly detection
	o Mitigation and recovery
	o Computer demos of substation intrusion and mitigation scenarios
6.4	• **Cyber-Security of Distribution Systems**
	o Outage management and service restoration
	o Distributed energy resources
	o Smart meters
	o Remote-controlled devices
	o Computer demos of cyber-distribution system security intrusion scenarios

- *Acknowledgment. "This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technology Office Award Number DE-0008574."*