Enabling grid of the future

Organizers: Brian Johnson, Srinivasa Salapaka, Blake Lundstorm, Matt Wytock, Zico Kolter, Murti V. Salapaka

Topic, Rationale and Format

Over time, the electric power grid has evolved into a top-down architecture where the system acts as a stiff source which provides a robust backbone and dictates power distribution, power generation and pricing of multitudes of power generation and load units. An array of strategies are in place that have led to reliable performance such that a highly stable voltage and frequency are assumed to hold by businesses and households that connect to the grid. The power infrastructure provides robust and stable operation that is offered in a complex networked system where loads can dynamically interact with the system without any prior communication to any other central grid entity. In this environment of highly changing load-profiles, the grid has a self-healing adaptive mechanism consisting of local controllers at the generating units which take corrective actions based solely on local measurements. These local methods include droop control strategies which exhibit a global emergent behavior in steady state. These conventional control strategies have yielded robust and reliable performance. However, in light of the increasing adoption of distributed generation and renewables, a paradigm shift in control strategies is needed which circumvents the assumption of unidirectional power flows.

Several factors such as the environmental impacts of conventional energy sources, the increasing viability and availability of renewables, and the decreasing costs of power electronics interfaces are incentivizing a decentralized system structure. Furthermore, the present architecture is too rigid to fully exploit the flexibility of power electronics circuits and emerging control power strategies. Thus, there is a need for a new scalable architecture for management of power generation, distribution, and load management where local energy sources and loads seamlessly incorporate economic objectives, connect and disconnect from the grid as needed, ensure stability, and maintain reliability of the existing grid. Key enablers to the realization of the grid of the future are power electronics based devices.

The controls community is already playing a key role in shaping the grid of the future. A large emphasis of the existing work is on optimal power flow and system control using economic criteria. In this workshop, the *realization* of systems that enable integration of distributed generation, while incorporating objectives related to economics and reliability, will be targeted. There is a considerable demand currently for such systems in critical infrastructures such as hospitals, self-contained isolated units employed by defense or space applications, and for areas of the world where there is scarce power availability. A considerable focus will be on power electronics based control architectures.

An attendee of the workshop will, by the end of the workshop, attain the fundamentals of how to design, implement, and analyze a power electronics based system that enables distributed generation, prioritization, and integration of heterogeneous power sources. The key modeling and control paradigms will be described and recent research results will also be elucidated. Key insights into how to monitor such systems using machine learning tools will be emphasized. Finally, directions on how modern control tools can be brought to bear will be proposed.

The workshop proposed is for a half day (4hrs) The organizers include researchers from National Renewable Energy Laboratory (NREL) and faculty and researchers from controls and computer science areas. The mix of expertise will provide a good mix of important and diverse perspectives to the grid of the future.

Abstracts and presenters

The organization of the topics to be presented follows:

1. **Grid of the future**

   Abstract: Here, the present state of the grid and the possibly disruptive changes in the near future that are impending will be highlighted. This discussion will set the stage for why new research and education in controls is needed in this area and the niche areas where controls can play a future role will be highlighted. The overall architecture of power flow of the present grid architecture will be summarized.

   Presenter: Srinivasa Salapaka, Murti Salapaka

   Time: 30 mins

2. **Control of energy delivery using power electronics**

   Abstract: The latest advances in digital control and power electronics circuits enable the development of flexible and high-bandwidth energy delivery systems. In any type of modular power electronics system, the instance of a single power converter forms the basic building block. Accordingly, this portion of the tutorial will provide a brief overview of the physical construction and characteristics of a power converter, pulse width modulation techniques, development of average models, and design of closed-loop controllers for power converters. The talk will be focused on ac systems which utilize dc-ac *inverters*. Using the presented material, the audience member will have the requisite knowledge to model a power electronics inverter, design its controller, and have a working understanding of the implementation issues at the single power converter level. A special emphasis will be placed on the typical assumptions which facilitate analytical design tools and their underlying physical interpretations. Furthermore, recent results which utilize the modern control framework for the formulation of optimal voltage controllers will be introduced. It will be shown that the optimal controller exhibits an inner-outer structure and corroborates the longstanding observation that nested loop controllers have superior performance. The modeling and control design framework will be presented with a level of generality such that any higher-level controller may be augmented to the primary-level controller which is presented.

   Presenters: Brian Johnson, Blake Lundstrom

   Duration: 1 hr.

3. **System with multiple generation sources**

   Abstract: Current electrical grids are semi-centralized with a top-down power flow structure, where large generating stations produce electrical power, high-voltage transmission lines carry power from distant sources to demand centers, and distribution lines connect individual customers. This grid architecture inherently does not support small power sources and does not exploit the proximity of the power sources to the loads. It relies heavily on the a priori estimation of loads and is not designed to accommodate large uncertainties in power generation or consumption. An alternate architecture is to implement plug and play, bottom-up grids that use local power generation for local loads and interconnect to exchange power. This architecture and its use of multiple modular renewable energy sources, such as wind and photovoltaics, with special emphasis on management of uncertainties of these resources will be presented. The design objectives and challenges in realizing such a system will be described. The main objectives include voltage regulation and achieving sharing/prioritization between multiple power sources. The challenges include complexity in terms of architectures (sharing on dc side vs ac side vs both) and control of power-electronics to enable multiple objectives stated above, preserve power quality, and ensure seamless transitions between grid tied and off-grid configurations. Conventional as well as new approaches based on modern robust control framework and nonlinear oscillator based strategies to address these challenges will be explained

Presenters: Brian Johnson, Blake Lundstrom, Murti Salapaka, Srinivasa Salapaka

Duration: 1:30 hr

4. **Monitoring and prediction with machine learning**

Abstract: Here, real-time paradigms for monitoring and prediction will be highlighted, focusing on fast approaches well-suited for practical applications related to power networks. Modern methods for analyzing large-scale time series data are emphasized and the formulation of problems in a machine learning framework will be discussed.

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Presenter: J. Zico Kolter, Matt Wytock
Duration 1 hr.

Short Biographies of Presenters

Brian B. Johnson (S'08, M'13) received the B.S. degree in physics from Texas State University, San Marcos, in 2008. For graduate studies, he received the M.S. and Ph.D. degrees in electrical and computer engineering from the University of Illinois at Urbana- Champaign, Urbana, in 2010 and 2013, respectively. He is currently an Electrical Engineer with the National Renewable Energy Laboratory in Golden, CO. He was awarded a Graduate College Fellowship by the University of Illinois in 2008, a Support for Under-Represented Groups in Engineering Fellowship in 2008, and a National Science Foundation Graduate Research Fellowship in 2010. His research interests are in renewable energy systems, power electronics, and control systems.

Blake Lundstrom (M'11) received the B.S. and M.S. degrees in electrical engineering from Colorado School of Mines, Golden, CO, USA in 2010 and 2013, respectively. He is currently pursuing his Ph.D. in electrical engineering (power systems). Blake is a Research Electrical Engineer in the Distributed Energy Systems Integration group at NREL, where he has been employed since 2009. His research at NREL is focused on integration of distributed and renewable energy resources into the electric distribution system and involves distribution system modeling, advanced power electronics development, modeling and evaluation of micro-grid systems, and the use of real-time power hardware-in-the-loop techniques for energy systems integration research. Blake is a registered Professional Engineer in the State of Colorado.

Srinivasa Salapaka received the B.Tech. degree in Mechanical Engineering from Indian Institute of Technology at Chennai, India in 1995, the M.S. and the Ph.D. degrees in Mechanical Engineering from the University of California at Santa Barbara, U.S.A in 1997 and 2002, respectively. During 2002-2004, he was a postdoctoral associate in the Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, USA. He joined the department of Mechanical Science and Engineering at the University of Illinois, Urbana-Champaign in January 2004. He is a recipient of 2005

National Science Foundation CAREER award. His research interests are nanotechnology, robust-control, and classification and aggregation of large data and multi-agent networks and micro-grids.

Murti V. Salapaka received the B.Tech. degree in mechanical engineering from Indian Institute of \ Technology, Madras, in 1991 and the M.S. and Ph.D. degrees in mechanical engineering from the University of California at Santa Barbara, in 1993 and 1997, respectively. He was a faculty member in the Department of Electrical and Computer Engineering at Iowa State University from 1997 to 2007. Currently, he is a professor in the Department of Electrical and Computer Engineering at the University of Minnesota, Minneapolis and holds the Vincentine Hermes-Luh Chair in Electrical Engineering. His research interests are nanotechnology, multiple-objective robust control, and distributed and structural control, passive identification of network topologies and micro-grids. He is a 1997 National Science Foundation CAREER Award recipient.

J. Zico Kolter is an Assistant Professor of Computer Science at Carnegie Mellon University. His research focuses on computational approaches to sustainable energy domains, and core challenges arising in machine learning, optimization, and control in these areas. On the application side, his interests range from improving the efficiency of generation, controlling power in smart grids, and analyzing energy consumption in homes and buildings. He leverages techniques from machine learning, reinforcement learning, time series prediction, approximate inference, and convex optimization, amongst others.

Matt Wytock is pursuing his Phd with Prof. Kolter. His research interests are related to machine learning and its applications to sustainable energy domains.

Target audience and expected enrollment.

The target audience is a typical controls area engineer or researcher. Minimal background if any from the power area will be assumed. Researchers and practitioners from the power area will find the modern systems and controls parts valuable. Researchers who are contemplating entering this area of work will find this workshop particularly useful. The emphasis on realization of systems in contrast to a theoretical exposition is another differentiator.

Expected enrollment is twenty five to thirty attendees.