LIST OF ABSTRACTS:

1) Bulk Power System Integration of Smart Grid Reliability Considerations

Eric Rollison | Engineer - Reliability Assessments | NERC
Princeton, NJ

The deployment of automation, or 'smart grid', on the bulk power system continues to grow. 'Smart' technologies have been implemented for some time at the substations (in the form of SCADA, or supervisory control and data acquisition) and more recently, a small penetration in directly on transmission circuits. Some examples of this include automated reconfiguration capabilities, Dynamic Thermal Circuit Rating (DTCR), phasor measurement units (PMUs), and Flexible AC Transmission Systems (FACTS), all of which are discussed below. A significant challenge is to reliably integrate smart grid technologies while maintaining reliability. Three fundamental characteristics of the smart grid infrastructure, besides the availability of smart grid technologies, are interoperability, communications and IT systems. However, much of the control systems have little designed security being designed for local control and not resilient to errors from unintentional miscommunications or IT errors or intentional attacks.

First, the strength of interoperability design of smart grids, unless carefully planned and operated, can provide a vehicle for intentional cyber attack or unintentional errors impacting bulk power system reliability, through a variety of entrance and exit points. These control systems must be improved to provide robust protection from IT and communication vulnerabilities. Second, new tools and analysis techniques will be required to design and manage the deployment of broad-scale smart control systems across the bulk power system. As it is a large non-linear system, the ramifications and design of smart grid on control systems must be modeled, simulated and designed to ensure that the expected performance improvements will be realized, without increasing the vulnerability of the bulk power system to significant reliability concerns, such as transient and long-term stability, small signal stability, voltage stability and component design issues such as short circuit considerations.

2) Overcoming challenges and seizing opportunities: Perspectives from the MIT Future of the Electric Grid Study

Timothy Heidel, Research Director, MIT Future of the Electric Grid Study

Abstract: The U.S. Electric Power System today faces a variety of emerging challenges (largely driven by new policy priorities) including the integration of large-scale renewable generation, more distributed energy resources, and plug-in hybrid electric vehicles. Recent (or anticipated) technical advances also offer significant new opportunities including advances in remote sensing and automation and technologies that promise to increase the responsiveness of demand to system conditions. Existing institutions and policies can be relied upon to meet some of the new challenges and seize many of the new opportunities. However, in some cases, advances face significant barriers that will not be easily overcome without new policies, regulatory changes, standards efforts, or additional research. Sometimes, these barriers are the result of difficult to anticipate interactions among the many new grid requirements and/or technologies. The upcoming MIT Future of the Electric Grid Study aims to identify and study those challenges and opportunities that may face significant barriers. This study, involving researchers from economics, policy, and engineering, is the latest in a series of in-depth multidisciplinary MIT energy studies designed to inform future energy options, research, technology choices, and public policy development. In this presentation, we will present some of our preliminary findings,

giving examples of both challenges we have found will likely be tackled successfully and examples of challenges that could face significant hurdles.

3) **Survival Strategies for Unanticipated Cyber-Physical Incidents**

Howard F. Lipson, Ph.D.
CERT, Software Engineering Institute
DRAFT – February 1, 2011

Efforts to modernize our nation's electric power infrastructure through the overlay of two-way digital communications and highly automated digital control are based on the promise of greater energy efficiency, a more reliable self-healing grid, energy conservation, and significant reductions in peak energy usage. However, as a consequence, we are evolving toward an electric power system composed of widely-networked, highly interoperable, cyber-based communication and control systems that are characterized by unprecedented complexity. These systems have exceptionally large attack surfaces and exhibit emergent behavior that is hard to predict, particularly given limited engineering and operational experience with many of the novel aspects of these cyber-physical systems.

Protecting such systems from high-impact cyber-physical incidents, whether malicious or benign in origin, requires us to go well beyond traditional cyber security approaches. *Survivability* is the ability of a system to continue to provide essential services despite attacks, accidents, and subsystem failures. Graceful degradation and the ability to recover from adverse events in a timely manner are key characteristics of survivable systems. Building a system that can survive a set of known types of incidents is a reasonably well-understood engineering activity, including methods for making the necessary tradeoffs. However, designing, building, and operating electric energy systems that can survive severe cyber-physical incidents that are hard to anticipate or predict (e.g., high impact but unforeseen, rare emergent events) remains a significant research challenge. This talk will discuss some promising strategic approaches, fundamental principles, and research challenges associated with designing practical systems that can survive potentially catastrophic cyber-physical events that may be difficult to anticipate or predict because of emergent behavior or the unforeseen actions of an intelligent adversary.

4) **What may emerge as renewables become large scale?**

Jay Apt, Carnegie Mellon University

Here is an abstract: A much expanded role for variable and intermittent renewables is technically possible. But, only if we adopt a systems approach that considers and anticipates the many changes in power system design and operation that will be required to make this possible, while doing so at an affordable price, and with acceptable levels of security and reliability. I will cover recent work that has used high time resolution data on wind and solar power to 1) determine that some power sources are better matched with these variable sources than others; 2) quantify the costs associated with wind's variability and identify the characteristics of the output power that affect costs; 3) suggest whether there might be wind droughts; and 4) examine if electric vehicles can play a role in wind or solar integration.

5) Examples of Emerging Problems Related to the Fundamental Limits of Hierarchical Control in the Changing Industry and During the Abnormal Operating Conditions -

Marija Ilic

6) Thrust Area 1: Smart Grid Simulator - Marija Ilic

7) Thrust Area 2: Demand Management - Dan Siewiorek. A convergence of low cost sensor and actuator technology with novel grid control protocols will allow informed consumers to reduce consumption and manage their usage reducing peak demand on the power grid. Consumers currently have little concept about how their behavior and choices impact their energy consumption. An informed consumer with the ability to control their choices will have a first order impact on how much and when energy is used. The consumer can range in scale from an individual to a household to a company to a municipality. The demand side will require advances in three technical areas: Monitoring and Wireless Sensors, User Visualization and Control, and Experimental Testbeds.

8) Thrust Area 3: Transmission and Distribution Management - Gabriela Hug. With the transition to the smart grid, the number of sensors in the distribution system as well as the transmission system will increase enabling increased situational awareness and provide potential for optimized operation of the grid. In this thrust, we investigate which type of information should be provided by sensors and how to take advantage of this information to optimally use the existing infrastructure for reliable transmission of electric energy. We are developing a vision for the structure of the future electric power system from the grid perspective, revisit the principles in operation of transmission and distribution and introduce new concepts to transform the once passive electric power grid into an enable of sustainable services.

9) Thrust Area 4: Secure Data Management and Mining - Franz Franchetti This thrust combines researchers from security, computer architecture, computing, software engineering, and sensor networks. Our goal is to find interdisciplinary solutions for security, safety and reliability issues of smart grids. The highly dynamic and de-central structure of smart grids with its active users and intermittent energy sources requires a collaborative management and negotiations among the participants. Security protocols, software frameworks, the role of data and computation and special purpose computer architecture are to be combined to reach the goal of a smart grid.

10) Thrust Area 5: New Policy Paradigms and International Collaborations - Marvin Sirbu

11) Synergies with the NSF Project – Rohit Negi

12) A New Way to Analyze and Monitor Cascading Failure - Ian Dobson
University of Wisconsin-Madison

Cascading failure is a sequence of dependent failures that is the main way that power transmission system outages propagate to form large blackouts. The bulk statistics of cascading failure appear to be well captured by branching process models. Number of transmission line outages can be thought of as a diagnostic to track the propagation of disturbances in the power system. We model the bulk statistics of cascading line outages with a Galton-Watson branching process.

The bulk statistical approach opens opportunities for monitoring the cascading of transmission line outages from about one year of standard TADS (Transmission Availability Data System) utility data that must be reported to NERC.Given assumed or estimated initial line outages, we quantify the propagation of outages from the data, and then use the branching process to estimate the probability distribution of the total size of the cascading outage.This calculation is a way to extend the standard risk analysis of initial failures to also include the effect of cascading. The amount of propagation of cascading outages is a metric of power system resilience.

13) Detecting Proximity to Instability in Power Systems from the Noise in Phasor Measurement Data

Paul Hines, Ph.D. Assistant Professor School of Engineering, University of Vermont

With the growing deployment of phasor-measurement units (PMUs) in power systems, there is a rapidly increasing quantity of high resolution, time synchronized sensor data available to system operators. Information in these data that could signal a critical transition such as voltage collapse or dynamic instability could be valuable to system operators who need to make timely, and costly, decisions to avert large blackouts. While there are established methods available for detecting proximity to critical points when accurate system models are available, in practice all system models include substantial uncertainty. Therefore methods that can detect signals in the time series data alone could add value to existing technology. With this in mind, this talk will present evidence that the noise in high-resolution time-series measurements may be useful in detecting proximity to instability. We build on methods from the literature on "critical slowing down" from statistical physics, in which systems that are nearing critical instability tend to amplify lower-frequency signals in the system noise. We provide evidence from a single-machine infinite bus model and the Western US blackout of Aug, 1996, which both show evidence of critical slowing down before major failures occur.

14) On Reliability Standards, Criticality and Cascading Failures in Constrained Power Grids

Huaiwei Liao, Sarosh Talukdar, Marija Ilic

The Northeast Power Blackout on August 14, 2003 exposed the weakness of the North American power system and the insufficiency of existing reliability standards. On the other hand, the blackout signals there are ongoing fundamental changes in the North American power systems. These changes combined with the current movements of the energy industry are posing tremendous challenges to the power system. A new understanding of the existing standards and their implications to reliability are needed to accommodate the changes in power industry and to address the challenge properly.

In response to the great challenge faced in the century-old power systems, one needs to answer the following questions:

a) How will the power system behave when transferring tremendous power in a long distance under the current reliability standards?

b) What characterizes the behaviors of power systems when they are stressed toward their operating limits?

c) What can be done to improve the reliability standard in order to avoid cascading failures?

We address the problem of cascading failure risk during operating large-scale power systems instead of planning stages in most of previous studies. We propose a stress test model incorporating security-constrained economic dispatch (SCED) to simulate the state movement of the power system under increasingly power transfer. The simulation results indicate the existence of sharp-transition characteristics of cascading failure probability for a wide variety of large-scale power systems ranging from artificial regular networks to practical power systems. Further simulations reveal that the common practice of security constrained economic dispatch is one of the key factors driving the system to the presence of criticality.

15) Identification of Complex Deterministic Behavior in Power Systems

R. Wilson, M. Sattler, T. El-Mezyani, S. Srivastava, D. Cartes
Florida State University – The Center for Advanced Power Systems

Abstract: Bifurcations and chaos in power systems have been implicated in many types of system failures (voltage collapse, angle divergence) as well as linked to harmonic presence. These kinds of nonlinear phenomena clearly have a nontrivial impact on power quality and stability. Furthermore, an increasing presence of power electronic devices used within power systems introduces additional nonlinear tendency and harmonics. Our interest is identifying and quantifying the presence of these complex dynamics, with hopes for informing control decisions. We consider a measure of dynamical complexity (approximate complexity - ApCx) of a single measurement based on nonlinear time series analysis. The estimate is based on K2, the Renyi entropy of order 2. We will discuss why a measure of entropy is not regarded as directly useful for measuring complexity. The methodology used is taken from its original use in physiology (approximate entropy - ApEn), with its implementation modified to make it a measure of complexity as opposed to a measure of entropy. The modification results from examining the structure of the correlation integrals used to compute K2. Extensions to multiple components will be discussed.

16) Unintended Consequences of New Reliability Rules

Howard F. Illian, President
Energy Mark, Inc.

As the industry moves forward to develop and implement enforceable reliability rules, there will be unintended consequences resulting from these new rules. In some cases the results of the new reliability rules will be declines in reliability from current levels. This paper and presentation will offer two case studies of the impact of new reliability rules that result in declines in reliability. The first of these examples is based on recent history on one of the North American interconnections. The second is a projection assuming the implementation of a rule set currently under consideration. Both examples will be evaluated from the larger framework of how they interact with other industry structures and reach equilibrium states.

17) A Survey of Techniques for Protecting Power Grid SCADA Systems

Joseph A. Giampapa and Gabriela Hug-Glanzmann

A SCADA (System Control and Data Acquisition) system provides a reliable and cost-effective means by which a power grid may be monitored and controlled from a central control point. If a SCADA system component malfunctions or is attacked and consequently produces inaccurate data, or incorrect control signals, control room operators can lose awareness and control of the power grid. They may, for example, take a “corrective” action that can unknowingly plunge the grid into a critical state if a decision is made based solely on bad data or a faulty signal. Further, if a power grid should fail as a result of a compromised or defective SCADA system, the process of turning power back on might take an inordinate and unacceptable amount of time as operators retest and revalidate the correctness of SCADA sensors and control actuators – an activity that must be done so as to locate and isolate the compromised or defective nodes.
Responses to awareness of SCADA system vulnerabilities have ranged from instituting new standards, to providing specific solutions for specific threats, with the most common approaches oriented toward closing potential system exploits and reducing the attack surface created by the interplay of a grid operator’s control and business data networks as well as the procedures used by subcontractors in servicing grid infrastructure. This article analyzes the guidance, and seeks to

identify some of the fundamental assumptions that motivate it. The identification of the motivating assumptions to the guidance, in turn, will provide insights into the completeness and adequacy of such guidance and techniques for protecting power grid SCADA systems, and if necessary, indicate potential problem or unaddressed vulnerability areas.

18) Integrating Random Energy into the Smart Grid

Kameshwar Poolla and Pravin Varaiya, UC Berkeley
Felix Wu, University of Hong Kong

Deep integration of renewable energy sources, and wind energy in particular, is one component of the Smart Grid vision. A fundamental difficulty here is that wind energy is highly variable-- it is not dispatchable, it experiences large changes over many time scale, and it is not easily predictable. The electricity grid must absorb this variability through a portfolio of technologies that include improved forecasts, novel market instruments, demand shaping, storage, local generation, and optimal grid operations.   This talk will present mathematical formulations of several problems that these technologies can address.

19) Cournot Gaming in Joint Energy and Reserve Markets

Mohammad Salman Nazir, McGill University

ABSTRACT: In a traditional oligopolistic market structure, Gencos maximize profits through strategic generation offers based on the Cournot or the Supply Function equilibrium. Market power is however not limited to balancing generation and demand in real time but also to reserve in order to balance generation and demand under contingency situations. In an electricity market where online generation and spinning reserve are priced separately, hydro and thermal generators can engage in simultaneous gaming on both commodities. In this paper we examine the strategic behaviour of such markets based on a Cournot-type equilibrium under which both the demand and the system reserve obey a known relationship with respect to its price. Under cases of extreme contingencies and high demand, we consider the possibility of load shedding or of the system operator buying reserve from an external continent-wide market or from the local demand. In addition, the Gencos' overall strategy may include selling reserve to the external market. The paper will be backed up by a number of case studies.

KEYWORDS: Cournot, Reserve Gaming, Load Shedding, Electricity markets

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19A) Stability, Volatility, and Efficiency of Electricity Markets under Real-Time Pricing,

Mardavij Roozbehani, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology

This talk is concerned with the system-level implications of dynamic retail pricing of electricity, a much advocated feature of future power grids. We begin with developing a mathematical model for the dynamic evolution of supply, demand, and clearing prices under a class of real-time retail pricing mechanisms characterized by passing on the real-time wholesale market prices to the end consumers. Under this mechanism, the interaction between the consumers and the producers creates a closed-loop feedback system with the Locational Marginal Prices as the state/output variables. We investigate the effects that this architecture could pose on price volatility and efficiency of the entire system and present several price stability criteria and discuss their implications. Our results indicate that price volatility is a function of the system's relative price elasticity, defined as the maximal ratio of the price-elasticity of consumers to the price elasticity of producers. As this ratio increases, the system becomes more volatile, eventually becoming unstable as the relative price elasticity approaches to one. The same notion of relative price elasticity can be used to characterize the system's robustness to external disturbances. We show that the higher the relative price elasticity is, the higher is the incremental L2-gain from the external disturbances to the market prices. The system could be stabilized and volatility could be reduced in many different ways, e.g., via static or dynamic controllers regulating the interaction of wholesale markets and retail consumers. However, different pricing mechanisms pose different consequences on competing factors of interest. In this regards, we present our results on the trade-offs between price volatility, robustness to disturbances, and economic efficiency in the sense of the aggregate welfare of consumers and producers.

As the penetration of new demand response technologies and distributed storage within the power grid increases, so does the price-elasticity of demand, and this is likely to increase volatility and possibly destabilize the system under current market and system operation practices; whereas grid friendly appliances responding to system frequency deviations are likely to mitigate the destabilizing effects of the markets to some extent. This talk shows how naive system architectures can lead to major problems, and highlights the importance of proper architecture design for efficient integration of advanced technologies.

20) Power System Performance with 30% Wind Penetration

Judith Cardell, Picker Engineering Program, Smith College
Lindsay Anderson, Biological and Environmental Engineering, Cornell University

As the penetration of wind generation increases, the variability of wind farm output is commonly expected to have negative impacts on the ability of the power system to reliably serve load at low cost. Many state level renewables portfolio standards nonetheless, generally require an increasing percentage of delivered energy to be generated from clean, renewable energy resources. Though there are numerous technology options specified in these portfolio standards, the potential for meeting them with wind power is receiving significant attention.

This paper analyzes the effectiveness of demand response, storage and generating technologies in mitigating the system cost and reliability impacts of up to 30% wind penetration, on an energy basis. The analysis method is a scenario-based Monte Carlo simulation of the 39-bus New England test system. The scenario attributes include three reserve margins and three levels of forecasted wind output at both on-shore and off-shore wind sites. The Monte Carlo simulation draws real-time wind power output realizations. The power system response to the deviation between the scheduled system dispatch with the forecasted output, and the real-time dispatch with the actual wind output is modeled via optimal power flow. The results show that demand response resources are integral to maintaining system reliability and preventing LMP spikes and extreme production cost excursions. Other system parameters, such as real and reactive power losses and the voltage profile are also modeled.

21) Learning from the Past to Prepare for the Future

Tom Overbye
University of Illinois Champaign

A large-scale interconnected electric power system is one of the world's most complex machines. And as smart grid technology proliferates the grid is becoming even more complex. This presents tremendous challenges from a modeling perspective. But a tremendous, and usually underutilized, advantage is because the system is continuously operated under similar conditions, much can be learned from past system behavior to better prepare for future challenges. This talk explores techniques for more efficiently utilizing this historical information.

22) Risk-based Mechanisms for Managing Volatile Supply in Power Markets

Uday V. Shanbhag, Assistant Professor Department of Industrial and Enterprise Systems Engineering University of Illinois at Urbana-Champaign

A challenge associated with integrating wind-based generation is the reliability-based impacts that are unpriced by the market. We develop an alternative framework that relies on risk-based mechanims which are aimed at mitigating this problem. The resulting class of game-theoretic problems are nonsmooth and stochasti in nature. We provide a characterization of solution sets of the resulting equilibrium problem. Additionally, we develop distributed regularization-based projection schemes for computing the associated equilibria in a scalable fashion. Policy insights associated with wind-power integration are also drawn from a 53-node network.

23) Interdependencies Between Technical, Economic, and Environmental Changes: Frequency Case

J. Ilic & M. Prica

24) Where to Next?

Leonard S. Hyman, CFA, Senior Advisor, Black & Veatch

The United States put its electricity supply industry through a two stage restructuring that began three decades ago with the introduction of independent power production as a supplier to the regulated electric utilities. Then, almost two decades ago, the second stage began, with the creation of wholesale power generators, followed up by restructuring efforts in many states and a reorganization of the management of the transmission sector and dispatch of power plants.

Unlike what occurred after other industries restructured and introduced competition, in the electricity sector, restructuring was not followed by dramatic cost and price reductions, or the introduction of significant new products and services. In addition, no new states seem willing to restructure their markets. In retrospect, the industry and policy makers ignored key principles of management, risk allocation and economics.

The electricity sector, now, has to deal with new challenges: modernizing for the digital economy, reducing carbon emissions, and keeping down costs for a consumer base already depressed by economic conditions. The electricity sector -- with help from regulators, government and various special interest groups-- will attempt to meet those challenges with an assortment of semi-coordinated fixes that appear to ignore key principles of management, risk allocation and economics. Where does that scenario take us?

25) Architecting the Future Power System

Eugene Litvinov, ISO New England

Smart grid technologies could dramatically alter the architecture of the existing power grid. One prominent feature of the smart grid is the unprecedented level of *uncertainty* brought by variable resources, such as wind and solar, *responsive demand* assisted with the Advanced Metering Infrastructure (AMI). Another salient feature of the future grid is the increasing variety and level of *distributed* resources, e.g., combined heat and power, photovoltaic arrays, electric vehicles, flywheels, etc. These resources will be located in the distribution system, but will function at the transmission level through virtual power plants, aggregators or micro grids. This high level of uncertainty (not only in value, but spatial as well) will require significantly more flexibility in system balancing mechanisms, which, in turn, may lead to comparatively higher reliance on corrective actions and Special Protection Systems (SPS), Remedial Action Schemes (RAS) and System Integrity Protection System (SIPS), new smart grid technologies like storage, EVs, DR, etc. The tradeoff between preventive and corrective control measures may change. Significantly higher flexibility will lead to a different electricity market designs, allowing for cleaner financial only forward markets. The complexity of such system can easily grow beyond control and lead to unexpected phenomena and undesired emergent behavior. New ways of formalizing complexity and quantifying survivability are desperately needed. This will help developing policies limiting the complexity to preserve controllability and observability of the system.

Future Grid will in turn require more flexible power system architecture. Design and operation of such system has to be built on the principles of survivability - instead of trying to eliminate blackouts (which is an impossible task), the system has to be able to contain the disturbances minimizing the impact on the operation. The very concept of reliability may have to be analyzed and updated to accommodate the distributed nature of future power systems. New control concepts and infrastructure has to be developed to accommodate new requirements.

Architecting new system architecture requires very focused effort by academia and industry and has to be done quickly in order to take into account long planning horizon.

26) Integrating PV on Distribution

Forrest Small, Director
Navigant – Energy Practice

Utilities across the country are seeking to install utility-owned distributed solar on a large scale and putting it in the rate-base. Distributed PV can be connected at three points in the distribution system depending on the location and size of the installation: substation interconnection, primary distribution interconnection, and behind the meter interconnection. Each point has a practical limit based on the impact of the PV on the distribution system. In addition to high cost, T&D concerns, communications, and regulatory challenges have limited the PV deployed in the past. Past research had indicated that distribution performance may degrade if PV exceeded certain penetrations on distribution circuits.

However, recent focused studies show that distribution voltage stays within system design criteria even with high penetrations of PV even when the PV is located far from a substation (see chart below). Smart Grid systems supporting better communications and control between distributed PV and the utility distribution system will further minimize potential impacts.

As distributed PV becomes a significant energy resource in utility systems, distribution effects from high penetrations of PV may not be as significant as once thought. More research and analysis must be done to determine the extent to which PV and energy storage can provide grid benefits.

27) Dynamic Line Ratings for a Reliable and Optimized Smart Transmission

Sandy Aivaliotis, Nexans

Abstract: While utilities today measure the load of each transmission line, they do not know the transmission transfer capacity in real time. Reliable Dynamic Line Rating (DLR) is a technology that provides the transmission owner and the ISO with the actual line transfer capability as it varies with weather conditions in real time. This information not only allows the operator to optimize the utilization of existing transmission assets but also can alert the operator to any impending sag non-compliances, the main concern of the NERC Alert issued October 2010. >

28) Performance Characteristics of State of the Art Wind Plants

Jovan Bebic, Ph.D. Principal GE Energy Energy Consulting

29) Evolving Toward a High Assurance Smart Grid through a Distributed Control System Architecture

Thomas M. Overman
Boeing Defense, Space & Security

Abstract – As electrical grids evolve through the introduction of additional "smart" sensors, actuators, and control systems, cyber security becomes an ever more significant factor, necessitating the incorporation of Information Assurance principles throughout the electrical system—from central station power generating facilities, through transmission and intelligent distribution systems, to building management systems, distributed generation, home area networks, and plug-in hybrid electric vehicles.

Before delving into the distributed system architecture discussion, a review is useful for the core principles of the High Assurance Smart Grid architecture. A precursor to determining the appropriate controls for any particular distributed device within this complex system is to determine the trust model (or un-trusted condition) within which it exists. The initial task will be to define trust and its components in the context of the core principles of a multi-level architectural framework to be used throughout the electrical system. Once the brief review is completed, a more detailed discussion of the implications using distributed intelligence within the Smart Grid for improving both electric reliability and cyber security is developed.

Once an assumption is made that every command and control (C2) system has a variety of failure modes, consideration should be given to determining where the use of explicit C2 can be avoided while still achieving some of the goals the C2 system is intended to provide. Many demand-response (DR) functions exist to enable operating utilities to reduce loads in anticipation of or in response to grid overload conditions. Auto-Responsive (AR) load control can provide the desired DR without the need to build hierarchical C2 capabilities all the way back to the control room. Thus the distributed nature of the recommended architectural approach incorporates both distributed-but-collaborative decision making and autonomous decision making.

30) Operation Challenges in Power Systems with Large-scale Renewable Energy Sources

Vaibhav D Donde
ABB Inc.

31) Electrical Models to Support Grid Deployment of Smart Grid Advanced Batteries

Chales Vartanian
A123 Systems

ABSTRACT: 123 Systems has deployed over 30 MW of Smart Grid compatible advanced energy storage systems. Deployment of these systems has required the development of battery system electrical models for use by grid owners and operators in their Interconnection System Impact Studies. This presentation will outline the challenge of implementing a new technology in context of a defined and relatively traditional modeling process; i.e. the FERC interconnection process. As A integration, a new set of grid-supportive capabilities must be translated into models and simulation procedures for use by grid owners and operators. Specific examples of early expanded modeling requirements outlined in this presentation include use of batteries for variable generator ramp-rate-management, support of meeting LVRT and UFRT requirements, and provision of inertia-equivalent. Looking fwd to making it back to the CMU Electric Industry Conference.

32)

Jim Calore, Mgr - Interconnection Planning
PSE&G

33) What Makes a Grid Smart?

Venkat Shastri, President and CEO
PCN Technology, San Diego, CA

There is significant interest in the transformation of our aging power grid into what has been termed as a “smart grid.” Before we begin to understand the opportunities and obstacles that lie in the path of a transformation of our grid, it would be important to understand exactly what the term smart grid means. In this talk, we explore, from a systems theoretic perspective, the necessary elements of a grid that might be considered smart, and suggest that a movement is required in the industry from the traditional metrics of SAIDI and SAIFI to control measures such as stability, steady state error, disturbance rejection and robustness. We argue that this is necessary for maintaining high levels of power quality in a grid with substantial generation from renewables and feasible within the next two decades given the advances in solid state power electronics, sensing, communication, controls and computing.

34) Reliable Power System Operations Challenges and Opportunities Associated with High Penetration of Renewable and Distributed Resources

Farrokh A. Rahimi, Ph.D. Vice President, Market Design and Consulting Open Access Technology International, Inc. (OATI)

35) Cognitive Energy Systems

Simon Haykin
Mc Master University
Canada

36) Trends in High-Performance Computing for Power Grid Applications

Franz Franchetti

During the last years commercial off-the-shelf (COTS) systems became incredibly powerful. A high-end desktop computer system in 2011 is built around a eight-core processor running at around 3GHz and a powerful graphics card with 400+ cores running at 1.3 GHz and consuming 300W power. Such a commodity desktop PC of today would have been among the 500 fastest supercomputers worldwide as late as in 2003. High-end machines have grown in power at a similar pace. The top machine broke the "petaflop-barrier" in 2009 (1 petaflop is 1015 additions per second), and we are well on our way to the 20-petaflop class machines. This incredible development has allowed commercial high-performance computing to become an important tool. In this talk we investigate the trajectory of computing systems. We overview the plans of researchers, industry, and government to reach the "exaflop" (1000x improvement) by 2018 and to shrink the largest supercomputers of today into the size of a single 19" rack. Further, we discuss the implications on software and for users/programmers.

37) Making the Concepts of Robustness, Resilience, and Sustainability Unseful Tools for Power System Planning, Operation, and Control

Lamine Mili
Bradley Department of Electrical and Computer Engineering
Northern Virginia Center, Virginia Tech

Advances in power electronics, computer and communications have opened new avenues for the monitoring, control and protection of critical infrastructures. For instance, the advent of low-cost computer-based sensors and actuators together with wireless communications devices are making possible the development of a new form of control based on multiagent technologies. If the latter are endowed with the ability to take collective actions geared toward a common goal, then control actions exhibiting emergent properties may result. They are emergent in the sense that they stem from the collective interaction of the agents, not from their individual actions. Another level of complexity is attained if the common goal is defined by the agents themselves as a response to an environment evolving in an unexpected way. In this talk, we will define the concepts of robustness, resilience and sustainability in power systems and we will outline a future research agenda that fosters a paradigm shift in interacting power and communications systems.

38) A Study of Smart Grids Benefit for China's Wind Development

Dr. Yunhe Hou
& Felix F Wu, Philip Wong Wilson Wong Professor in Electrical Engineering
The University of Hong Kong

Abstract: To meet the enormously demand increment, as well as environmental constraints, Chinese government has set policies to increase renewable energy penetration. The wind power has been largely introducing to China's power system and more ambitious target has been set. Different from the US and Europe, due to the significantly uniform distribution of wind energy in China, wind generation in China is mainly invested by the government and installed centrally at some locations, where are far from the load centers. This intermittent long-distance transmission system greatly challenges the system operation.

In this presentation, based on the currently status and the planning of China's wind power development, a comprehensive framework of system with large scalar centralized wind integration is proposed. On the generating side, consider the available resources, a combination of wind generation, thermal generation and storage systems is employed to smooth the output of the huge wind farm. For the transmission system, a criterion is established to meet the requirements for economic and reliable operation. For the demand side, the load response strategy is proposed follow the renewables fluctuation. The whole system is evaluated by the

concept of operating risk, a new system operating paradigm – risk-limiting dispatch is used to meet the risk, as well as economic constrains.

The systematic framework proposed in this presentation is based on the wind power development in China. The benefits of major components of the smart grid, such as storage, load response, are identified. Furthermore, the methodology can be generalized to the system with large-scalar wind power integration.

39) Are Policies to Encourage Wind Energy Predicated on a Misleading Statistic?

Kevin F. Forbes
Marco Stampini
Ernest M. Zampell

Kevin F. Forbes and Ernest M. Zampelli are with the Center for the Study of Energy and Environmental Stewardship and the Department of Business and Economics at The Catholic University of America, 620 Michigan Ave. NE, Washington DC. Marco Stampini is Senior Research Economist at the Development Research Dept of the African Development Bank.

In response to the very real challenge of climate change, the share of electricity generation from wind turbines is expected to increase substantially over the next few decades. For example, in October 2008, the California Public Utilities Commission and the California Energy Commission recommended a 33 % renewable energy requirement as a key strategy to reduce greenhouse gases. The plan, if implemented, would increase the wind energy capacity available to the California Independent System Operator (ISO) by almost 500 percent by 2020 with wind energy capacity accounting for approximately 18 percent of installed nameplate capacity (Hawkins, 2008). According to the American Wind Energy Association, renewable energy policies currently exist in 28 U.S. states with wind energy being a significant beneficiary. Growth in wind energy production is also enhanced by an income tax credit of 2.1 cents per kilowatt-hour of wind energy production. Legislation is also being considered in the United States Congress that could increase the share of electricity from its 2009 share of total electricity generation of about 1.8 percent to 20 percent. The European Union has a goal of 20 percent renewable energy by 2020 with wind energy serving as a key source of the increase.

These proposed increases in wind energy are implicitly predicated on the belief that wind energy, while not capable of "upward dispatch", is fairly predictable. But is it? According to most analyses, the answer clearly is yes. Cali, *et. al.* (2006) have indicated that the root-mean-squared-errors (RMSE) of the day-ahead wind energy forecasts at one of the German TSOs (unidentified) have declined from approximately 10 percent of installed wind capacity in 2001 to approximately six percent of installed wind energy capacity in 2006. This finding has been cited by the European Wind Energy Association (2007) as evidence that wind power is a reliable source of electricity supply. Lang (2006) presented a forecasting approach that had a weighted mean forecast error of approximately six percent for Ireland. It was noted that the forecasting method offered the system operator the ability to accommodate higher wind penetration levels. The Midwest ISO has reported that the mean absolute percentage error of its day-ahead wind forecasts is approximately 7.06 percent of its installed wind energy capacity. In a report commissioned by the National Renewable Energy Laboratory , Porter and Rogers (2010, p. 5) have reported the mean absolute wind forecasting errors in ERCOT, the system operator that

40) Distributed capacity resources for emerging problems in distribution systems

Luis AFM Ferreira
Pedro MS Carvalho

Abstract: As distributed energy resources grow in number and importance so do number of potential problems in distribution systems. The distribution network, which is designed radially, with one power injection point and many consumer points, and expected load levels at each consumer point, will be subject to different constraints. Loads may become negative and of a different order of magnitude. At the distribution level, dealing with these new constraints may lead to curtailment of new generation, curtailment of loads due to malfunction of the network, strong investment in network reinforcement, and new capabilities to enable fast, intelligent network reconfiguration.

Another idea is to promote the development of distributed capacity resources. Those resources will take place near the distributed generation units, or in other critical points in the network. Their role is to supply power should it be needed. Thus they need not be very efficient; rather they should be inexpensive and reliable. They could be based on batteries, flywheels or even gas-fired generators (many of which already exist for emergency operation). These resources can satisfy the requirements for low investment, high reliability. Together with a smart grid technology, including fast reconfiguration and load control, they will enable the continual growth of distributed energy resources and enhance the system security and reliability.

41) Modeling and estimation of Microgrid Parameters Using Message Passing Algorithms

Ying Hu, Anthony Kuh, Aleksander Kavcic, University of Hawaii
Dora Nakafuji, Hawaiian Electric Company

ABSTRACT: This presentation looks at models and estimation of grid parameters beyond the last substation which is often referred to as the distribution system. The distribution system can be described by an electrical power grid where the grid can be represented by a radial graph with many of the nodes of the graph representing electrical loads. The distribution system is changing with the incorporation of distributed generation (wind, solar) and possible storage. We refer to this system as a microgrid. The smart grid requires sensors such as AMI to monitor electrical parameters of the grid. The AMI will be located at some of the nodes of the graph. A goal is to come up with models that effectively incorporate different components of the microgrid and develop computationally efficient algorithms that can estimate parameters of the microgrid. Both the load and distributed generation are random and require probabilistic models to describe them.

Based on this we use a factor graph to model the microgrid. This includes modeling the electrical power grid, sensors, and the power generated by distributed generation. Sensor readings are represented by observation variables. Factor functions represent the electrical relationships of the electrical power grid. Other factor functions model correlations between different distributed generation sites (e.g. PV panels located on different houses). Representing correlations by graph edges will result in the graph having loops. We represent the state of the nodes as complex voltages and currents. The behavior is then given by the factor graph and factor functions. State estimation can then be performed by using appropriate message passing algorithms (e.g. belief propagation). To make the algorithms plausible and computationally tractable several issues are addressed including:

(a) We must develop spatial and temporal correlations for wind velocity and solar irradiance.
(b) Factor functions describing electrical relationships should be known.
(c) Plausible assumptions need to be made concerning the probability distributions of voltage and current.
(d) Models or real data are needed for electrical loads.
(e) To make the computations tractable we need to linearize nonlinear factor functions.
(f) Computationally efficient algorithms such as the belief propagation algorithm need to be

developed for the microgrid factor graph.
(g) Results should be validated with data from real microgrids.

Once effective models and estimation algorithms for the microgrid have been developed, then control algorithms can use this information to make informed decisions about microgrid energy management. Other issues such as fault detection and network anomalies can also be addressed.

42) Redefining the notion of observability for networked estimation

Usman A. Khan

Abstract: We introduce a new model of social learning and distributed estimation in which the state to be estimated is governed by a potentially unstable linear model driven by noise. The state is observed by a network of agents, each with its own linear noisy observation models. We assume the state to be globally observable, but no agent is able to estimate the state with its own observations alone. We propose a single consensus-step estimator that consists of an innovation step and a consensus step, both performed at the same time-step.
We show that if the instability of the dynamics is strictly less than the Network Tracking Capacity (NTC), a function of network connectivity and the observation matrices, the single consensus-step estimator results in a bounded estimation error. We further quantify the trade-off between: (i) (in)stability of the parameter dynamics, (ii) connectivity of the underlying network, and (iii) the observation structure, in the context of single time-scale algorithms. This contrasts with prior work on distributed estimation that either assumes scalar dynamics (which removes local observability issues) or assumes that enough iterates can be carried out for the consensus to converge between each innovation (observation) update.

43) Optimum Reduced-order DSE for Power Systems with PMU Measurements

Jing Huang1, Stefan Werner2, and Yih-Fang Huang1
1Dept. of Electrical Engineering, University of Notre Dame, Notre Dame, Indiana
2Dept. of Signal Processing and Acoustics, Aalto University, Helsinki, Finland

ABSTRACT: The introduction of phasor measurement units (PMUs) in power systems can significantly improve the capability of capturing the dynamics of the system. However, adding PMU measurements to traditional measurements increases the dimension of the state estimator that typically employs Kalman filters, thereby increases significantly the computational complexity in state estimation and making it more vulnerable to numerical instability. This paper proposes a reducedorder dynamic state estimator for such a scenario. This novel estimator is examined and its performance is compared with the traditional Kalman filtering scheme that includes PMU measurements. The results have shown promises of the proposed algorithm as a viable approach to dynamic state estimation with the presence of PMU measurements.

44) Integrating Wind Power: A Potential Role for Controllable Demand

Alberto J. Lamadrid and Tim Mount
Dyson School of Applied Economics and Management
Cornell University

Abstract: With high penetrations of wind generation, it is likely that some potential power production from this source will be spilled unless the inherent variability of this source is mitigated in some way. Installing dedicated on-site storage or backup generators, for example, is one effective but expensive way to do this. Without some form of mitigation, some wind generation will be spilled even if its operating cost (i.e. the offer into the wholesale market) is zero. The two main

reasons are 1) transmission congestion when demand is high limits the ability of the network to transfer available wind power to customers, and 2) limiting the size of wind contingencies (i.e. cutouts to protect turbines from damage at high wind speeds). Under these conditions, another way to reduce the amount of wind spilled is to use controllable demand to shift demand from peak to off-peak periods using thermal storage and electric vehicles, for example. Controllable demand can also be used to provide other ancillary services, like ramping services to offset fluctuations in wind generation. These demand technologies are likely to be more cost effective than dedicated equipment because a large part of their capital cost is already covered by their primary uses for space conditioning and transportation. Using the Cornell SuperOPF, operations on a test network are simulated for a typical day to compare the effects of 1) controllable load, 2) on-site storage, and 3) upgrading transmission capacity. The different scenarios are evaluated in terms of 1) the percentage of potential wind generation spilled, 2) the total operating cost of production, and 3) the amount of installed capacity needed to maintain operating reliability. The results show that controllable load improves (reduces) all three criteria by alleviating congestion and mitigating wind variability. In contrast, the beneficial effects are smaller for both on-site storage, because it does not shift load to off-peak periods, and for upgrading transmission, because it does not mitigate wind variability.

45) Title: The potential of hydro power for the integration of wind generation –
Gabriela Hug

The variability and intermittency of wind generation is a major challenge in the integration of these renewable resources. Potential resources to balance the variability and intermittency include storage devices, demand response and conventional fast-ramping generation resources. In this talk, we investigate the potential of hydro power to provide the required balancing capabilities. Current research in terms of hydro power in connection with wind generation mainly concentrates on pumped hydro which is a net power consumer and very restrictive in terms of location. In contrast, we explore the potential of cascaded river power plants. At the same time, the objective is to reduce the environmental impacts of river power plants. We derive a model of the river from fluid dynamics and incorporate it into a model predictive control scheme in order to predict and optimally schedule the available hydro power.

STUDENT SESSION:

A. Competitive equilibria for stochastic dynamic markets: The integration of wind power
Gui Wang
Department of Electrical and Computer Engineering and the Coordinated Science Laboratory, University of Illinois at Urbana-Champaign

We are moving towards a radical transformation of our energy systems. The success of the new paradigm created by the Smart Grid vision will require not only the creation and integration of new technologies into the grid, but also the redesign of its coupled market structures. Economic models able to capture the new physical reality are a first requirement for the design of a reliable, and "smart" electrical grid.

In this talk, we focus on the integration of wind energy resources in a multi-settlement electricity market. Under standard assumptions of competitive markets, we study the dynamic competitive equilibrium for a stochastic market model, and obtain closed form expressions for the supplier and consumer surpluses. Numerical results based on these formulae show that the value of wind generation to consumers falls dramatically with volatility. Several research questions are presented - their solution will require collaboration among researchers in economics, power and energy systems, and decision and control.

Based on the two recent papers:
* A Control Theorist's Perspective on Dynamic Competitive Equilibria in Electricity Markets

https://netfiles.uiuc.edu/meyn/www/spm_files/MarketsIFAC2011/MarketsIFAC2011.html
* The Value of Volatile Resources in Electricity Markets

https://netfiles.uiuc.edu/meyn/www/spm_files/wind2010/Wind10.html

B. **The Effect of Wind Power Penetration and Interconnection Location on Power System Transient Stability**

Daniel Schnitzer
Carnegie Mellon University
Department of Engineering & Public Policy
Carnegie Mellon Electric Industry Center (CEIC)

Power system stability during faults such as generator outages and transmission line failures is protected largely by the inertia of heavy generator rotors like those found in coal power plants. Because non-hydro renewable resources provide the power system with much less inertia, a large fault could induce damaging oscillations in a system with a high penetration of renewables that would otherwise have been dampened by rotor inertia. As the grid begins to lose high inertia resources and gains low-inertia resources like wind power, it is important to understand not only how the quantity of wind affects transient stability, but also whether the location of wind farm interconnections has a significant effect on transient stability.

Time-domain simulations on a fully dynamic, modified IEEE 14-bus test system were conducted to measure the effect of a fault on metrics for system stability with varying quantities of wind power and wind interconnection buses. Metrics chosen were the generator frequency deviation and Critical Fault Clearing Time (CCT). Scenarios vary the installed capacity of wind power from 0% to 36% of total installed capacity. At each level of installed capacity, the location of the wind farm interconnection is varied across each of the high voltage buses in the IEEE 14-bus test system. The Power Systems Analysis Toolbox (PSAT), an open-source Matlab-based dynamic simulation program, was used to conduct these simulations over a 20-second timescale.

As wind penetration increases, CCT tends to decrease and bus frequency deviation tends to increase. Also, these simulations indicate that there may be a "tipping point" of wind penetration, above which the CCT is drastically reduced. The location of the wind farm interconnection bus has a moderate impact on CCT and frequency deviation. While these results were found for a small standard test system, they indicate that more detailed and rigorous studies examining the impact of wind farm interconnection location on transient stability are warranted in power system planning activities. The recent announcement of a 6,000 MVA offshore transmission line from New York City to Delaware is likely the beginning of large3 scale offshore wind power in the US. With a limited number of interconnection buses to choose from, the results of these studies may suggest that, from the perspective of power system transient stability, the bus that corresponds to the best system performance should be chosen as the interconnection point for an offshore wind farm.

C. Equity and Efficiency in Dynamic Pricing

Shira Horowitz
CEIC CMU

We study tradeoffs between efficiency and equity under dynamic pricing of residential electricity. Retail real time pricing of electricity is theoretically more economically efficient than flat rate pricing since customers will only use the quantity of electricity that they value at or above the current marginal cost of power. This economic efficiency may come at the cost of equity: compared to the status quo of flat rate pricing, some customers will end up spending more on electricity under real time pricing, while others will spend less. We use hourly load data from 2500 Commonwealth Edison residential customers on a standard flat rate electricity tariff from 2007 and 2008. We calculate which customers would have been better off and which customers would have been worse under real time pricing and look at the general characteristics of these customers.

D. Adaptive Robust Optimization for the Security Constrained Unit Commitment Problem

Dimitris Bertsimas, Eugene Litvinov, Andy Sun, Jinye Zhao, Tongxin Zheng

Abstract: Unit commitment, one of the most critical operations of an electric power system, faces new challenges as the supply and demand uncertainty increases dramatically due to the integration of variable generation resources such as wind power and price responsive demand. To meet this challenge, we propose an adaptive robust unit commitment model and a practical solution methodology. We present extensive numerical study on the real-world large scale power system operated by the New England ISO. Computational results demonstrate the economic and operational advantages of our model over the traditional approaches.

E. Requirements and Adaptations of the Power Grid Due to Integration of Distributed Generation and Storage Technologies

Akhilesh Magal
Masters of Science
Environmental Engineering - Green Design
Carnegie Mellon University

With the integration of renewable energy generation and storage units onto the grid, the complexity and uncertainty of the grid is known to increase. This fact coupled with the growing needs of consumers and utility companies in the area of advanced metering, automation and detailed billing demand an adaptation to the current power grid. A wide range of technologies, policies and processes are needed to address these requirements at all levels.
With the different options available in technology, policies and processes, it becomes imperative to make the right choices which can be replicated and deployed on a large scale.
This talk presents the potential changes in technology, policy and processes that are needed to meet these needs and examines the early steps taken by the industry in this direction.