Electrical Power Affiliates Program

KANSAS STATE UNIVERSITY December 2014

In this issue

Integrating equipment and software in the Smart Grid Lab

Creating a smart overcurrent protective scheme in a radial distribution system

— By Emilio C. Piesciorovsky, Ph.D. candidate

We are in the era of smart products: smartphones, smart TVs and smart meters. We're also in the era of smart systems: smart buildings, smart houses and the smart grid.

Technology converts needs into smart applications. Smart products and systems have more functions and can make more decisions by themselves. A non-smart overcurrent protection system could be made by fuses. But a smart overcurrent protection system could be made with protective relays that have control, communication, protection and measurement functions.

In my research I will integrate equipment and software of Rathbone Hall's Smart Grid Lab. It is based on a power grid application: smart overcurrent protective scheme in a radial distribution system. Overcurrent relays in a radial distribution system sometimes cannot perform their relay trips for a fault situation, such as when breakers switch from one circuit path (circuit topology) to another, or equipment like transformers, lines and generator impedances were modified. This is because the fault impedances have changed, and overcurrent settings of relays need to be updated to work properly.

The objective of my research is to implement and verify a smart overcurrent protection system for a radial distribution system that would allow the relays to detect different circuit topologies and sequence impedances for setting relays by themselves.

My goals include:

- Implementing an algorithm to identify circuit topologies.
- Implementing an algorithm to calculate unknown sequence impedances.
- Implementing an algorithm to auto-set overcurrent relays.
- Applying a real-time simulator with relays in the loop to create the power and protection system.
- Verifying the relay settings by using a real-time simulator with relays in the loop.

Implementing a smart overcurrent protective scheme in a radial distribution system could present a great advantage for utilities. Overcurrent protections in relays could auto-set instantaneously based on identifying different circuit topologies and calculating unknown sequence impedances. It is crucial that overcurrent relays could make setting decisions by themselves to develop smart grid applications in protection systems.

Moreover, engineers use an adaptive multichannel source, or AMS, to verify their relay settings before placing relays in substations. AMSs have limitations because they can't simulate the power system and fault scenarios based on a real-time power system model.

During my research, I will use a real-time simulator with relays in the loop instead of an AMS. The real-time simulator has the advantage that each relay could be also verified working with other relays and in real-time scenarios.

Finally, I would like to thank Noel N. Schulz, director of the Smart Grid Lab and the Kansas State Electrical Power Affiliates Program.

Letter from the Director

Welcome to our annual Kansas State University Electrical Power Affiliates Program (EPAP) newsletter! What a great time to be involved in activities in the electric power industry! Our university is excited to work with eight industry partners to help advance workforce and research activities in the electric power industry.

While the EPAP program started within the Department of Electrical and Computer Engineering, we were excited to see our activities expand across our eight departments and other engineering units recently. Over the last two years we have funded research projects within architectural engineering, biological and agricultural engineering, civil engineering, computer and Information systems, electrical and computer engineering, engineering extension, and mechanical and nuclear engineering. I encourage you to read these summaries and learn about the projects addressing today and tomorrow's challenges in the electric power industry.

Besides our research projects, developing our future electric power industry workforce continues to be a priority for the Kansas State EPAP program. Our annual EPAP Day in the engineering atrium gives undergraduate students as well as graduate students a chance to learn about job opportunities from electric power companies, consulting companies and equipment manufacturers. In April 2014, 23 Kansas State students, sponsored by EPAP, attended the IEEE Power & Energy Society Transmission and Distribution Conference in Chicago. Kansas State also sponsored the IEEE PES 2013 North American Power Symposium where almost 200 power engineering students, faculty and industry representatives networked and shared state-of-the-art research advancements in the field.

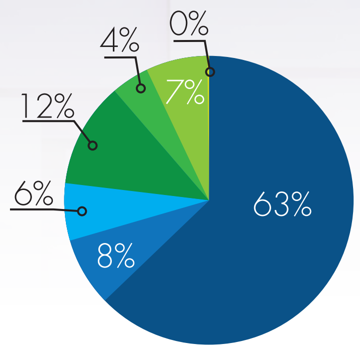
Having up-to-date facilities to train tomorrow's workforce is essential with today's evolving technologies related to smart grid applications. Our Burns & McDonnell Smart Grid laboratory continues to grow in types of equipment and uses across the fields of protection, communications, controls and advanced computing.

Thanks to our thriving industry-university partnerships, we are excited to continue to advance workforce and research activities in the area of electric power.

Noel N. Schulz

Noel Schulz

EPAP Expenses 2013-2014



GRAD Payroll	$68,375.46
UG Payroll	$8,519.36
Student Travel	$7,000.03
Supplies	$12,773.81
Tuition	$4,845.60
Admin	$7,638.09
Other	$63.60
Total	$109,215.95

Students, industry connect at annual EPAP Day

The fourth annual Electrical Power Affiliates Program, or EPAP, Day, occurred on Sept. 11, 2013. The event invited students and corporate EPAP members to participate in a minicareer day coordinated by the Department of Electrical and Computer Engineering.

Students in electrical and computer engineering programs as well as other programs in the College of Engineering visited with some of the most prominent companies in the power industry during the event. EPAP Day included several activities to benefit students and introduce them to careers in the power industry. Specifically, students had an opportunity to visit with fellow peers who have interned at one of the EPAP-member companies, as well as engage in a networking pizza party the evening before EPAP Day.

EPAP Day activities included member booths for students to visit with company human resources representatives and engineers as well as mock interviews with each company to help students gain practical interview experience. Other activities included classroom visits, presentations and an early engineer career panel where faculty, staff and students learned firsthand the challenges facing both the power industry and recent graduates entering the field. All College of Engineering students received a free lunch. As a bonus, students could win prizes such as a 32-inch TV, iPod Touch and a Kindle Fire.

"Students in the College of Engineering showed great excitement and enthusiasm for EPAP Day, as engineers from the electrical power industry not only visited classrooms, but they also interacted with students at corporate displays throughout the day," said Noel N. Schulz, Kansas State University's first lady and EPAP director. "This helps students at all levels learn about engineering careers and in particular electrical power industry careers."

EPAP corporate members at the executive level include Burns & McDonnell, KCP&L, Omaha Public Power District and Westar. Companies at the member level include and Fishnet Security, Sega Inc. and Schweitzer Engineering Laboratories.

EPAP research publications and presentations

Publications

1. A. Sydney, C. Scoglio, and D. Gruenbacher. "The Impact of Optimizing Algebraic Connectivity in Hierarchical Communication Networks for Smart Grids," IEEE PES Innovative Smart Grid Technologies (Accepted for publication December 2012).
2. A. Sydney, J. Nutaro, C. Scoglio, D. Gruenbacher, and N. Schulz. "Simulative Comparison of Multiprotocol Label Switching and OpenFlow Network Technologies for Transmission Operations," IEEE Transactions on Smart Grids (to appear).
3. A. Sydney, D. S. Ochs, C. Scoglio, D. Gruenbacher, and R. Miller. "Software Defined Networking (SDN) in GENI: Experimental Evaluation of OpenFlow Technology for Smart Grids," June 2012, submitted to Elsevier Computer Networks Special Issue on Future Internet Testbeds (Under review).
4. A. Sydney. "The Evaluation of Software Defined Networking for Communication and Control of Cyber Physical Systems," April 2013, Dissertation.
5. D. S. Och, and B. Mirafzal, "A Technique for Connecting a Three-Phase Inverter to the Grid with Few Sensors and No Static Transfer Switch," Submitted to K-State Attorney 2012.
6. D. Ochs, and B. Mirafzal, "A method of seamless transitions between grid-tied and stand-alone modes of operation for utility-interactive three-phase inverters," IEEE Transactions on Industry Applications, (in press) 2013.
7. 2013 EUEC proceedings, "OPPD Intern Benchmarks Healthcare Consortium for Energy Efficiency Success."

Presentations

1. "Software Defined Networking Vision for Smart Grids," FishNet Security, FireMon, Juniper, and Brocade workshops, November & December 2012.
2. "Experimental Evaluation of Software Defined Networking for Smart Grids," K-State Smart Grid Lab Inauguration, October 2012.
3. "Software Defined Networking in GENI: Using OpenFlow to Support Cyber Physical Systems Traffic," GENI Engineering Conference, July 2012
4. D. S. Ochs, P. Sotoodeh, and B. Mirafzal, "A technique for voltage-source inverter seamless transitions between grid-connected and standalone modes," Accepted for presentation at the IEEE Applied Power Electronics Conference, APEC, March 2013, Long Beach, California.
5. Denise Case, Scott A. DeLoach. "Applying an O-MaSE Compliant Process to Develop a Holonic Multiagent System for the Evaluation of Intelligent Power Distribution Systems." Workshop on Engineering Multi-Agent Systems (EMAS 2013) . May 6-7, 2013, Minneapolis, Minnesota.

EPAP 2012-2013 project summaries

A closer look at recently funded research

Smart grid communication, control and cybersecurity analysis and experimentation on GENI


Faculty involved: *Caterina Scoglio and Don Gruenbacher*

The project's goal was to evaluate software defined networking for communication, control and cybersecurity in cyberphysical systems where the system under consideration is the smart grid. The researchers have demonstrated through simulation that a relatively inexpensive OpenFlow switch can perform as well as a Multiprotocol Label Switching, or MPLS, switch. In particular, researchers developed a hybrid simulator that integrates the continuous time behavior of the power grid with the discrete event behavior of the communications network. The resulting power system analysis and network performance results indicated that OpenFlow performs as well as MPLS.

The engineers extended the research to real-world networks and demonstrated that the current OpenFlow hardware can provide similar services to that of MPLS. In particular, the researchers deployed a real-world smart grid prototype on the Global Environment for Network Innovation, or GENI, testbed using power resources from Kansas State University and OpenFlow network resources from both K-State and GENI. The engineers developed an OpenFlow controller and demonstrated services such as auto-route, auto-bandwidth, flow preemption, load balancing and failure mechanisms on GENI. They deployed these services simultaneously with their power system's protection and background traffic. The resulting power system analysis demonstrated that OpenFlow is able to provide the performance necessary to efficiently support transmission operations in the smart grid prototype. The researchers also obtained four hybrid OpenFlow switches to compare the performance of MPLS to OpenFlow for fast-reroute. From the local testing in K-State's Smart Grid Laboratory, fewer packets were lost using the fast-reroute OpenFlow mechanism when compared to MPLS.

2012-2013 EPAP architectural engineering and construction science project funding

Faculty involved: *Russ Murdock*

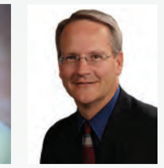
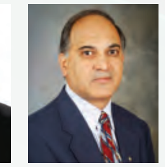
Electrical rough-in lab/demonstration models summary:

The EPAP funding gave an undergraduate architectural engineering student the opportunity to design and construct two mobile electrical rough-in demonstration modules. Each module is approximately 30 inches wide by 60 inches long by 72 inches tall, and is built on a wooden frame that mimics typical wall construction as it relates to stud spacing and layout. The premise is that one lab demonstrates rough-in practices and wiring installation for convenience power circuits and equipment, including a main lugs-only service panel and an associated separate service disconnecting means. The second lab demonstrates basic rough-in and wiring for light fixtures and their associated control and switching devices as well as a main circuit breaker-style service panel. Both labs are provided as three-phase panels, but are wired to allow for connection to a 120-volt receptacle that energizes a single phase for demonstration purposes. These practices and concepts are often foreign to many architectural engineering and construction science students who are interested in building electrical systems because these systems are often hidden in the cavities of the walls and ceilings of the spaces they are powering/lighting. The mobile labs give researchers a chance to wheel these showpieces to any classroom for use in a multitude of classes and to a wide audience of undergraduate architectural engineering and construction science students. The labs were designed with future proofing in mind so that the open construction method allows devices and infrastructure to be added to keep the installation and associated equipment in line with current construction practices and current device technologies. The labs have been used extensively in three separate architectural engineering and construction science classes and have resulted in very positive feedback from the affected students.

Electrical load monitoring/metering equipment summary:

The EPAP funding allowed the architectural engineering and construction science department to purchase three different load monitoring/metering technologies to deploy throughout classrooms and the west wing of Seaton Hall. The department purchased three sets of three-phase CTs and associated load-monitoring software to install in three different panels serving most classrooms. The monitoring equipment allows people—through a Web browser—to dial in on actual power usage for department infrastructure, which provides a window into the complicated and confusing world of power diversity and demand factors versus connected load totals. The department also has purchased two different models of plug-in kilowatt meters: one in the form of a single plug and receptacle, and the other in the form of a power strip. With the increasing complexity of ASHRAE's Standard 90.1 and its focus on reducing the unnecessary draw of plug loads when not in use, the meters let students look at consumption data from nearly any type of plug-connected equipment. The meters also serve as the foundation for a discussion on vampire losses and how good distribution systems design might take unnecessary receptacle and plug loads offline when not in use. The equipment is not yet installed and is awaiting final facility approval. Once installed, the data will be useful to more than four classes and more than 100 students each semester.

Holonic multiagent control of intelligent power distribution systems

Faculty involved: *Sanjoy Das, Scott DeLoach, Anil Pahwa*

The EPAP funding supplements a larger National Science Foundation research project to develop a simulation platform for power distribution systems, upon which the performance of various multiagent-based control strategies to be developed may be evaluated.

Ermias Gebreab, a graduate student in electrical and computer engineering, developed and implemented Matlab/Simulink software tools to simulate the physical power distribution system. The program can simulate the daily electricity consumption patterns of a power distribution system with several domestic consumers along with a high penetration of distributed renewable energy generation. The program is capable of simulating distribution systems under a variety of conditions, such as sunny or cloudy, and in islanded mode of operation. Ahmadreza Malekpour, graduate student in electrical engineering, also worked with Gebreab on the project.

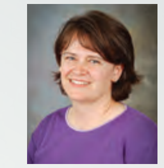
Denise Case, doctoral student in computing and information sciences, and Matthew Brown, recent graduate in computing and information sciences, integrated the physical simulation tool with the Java-based multiagent system architecture. They developed a Java wrapper around the Matlab/Simulink software tool to integrate it with the Java-based holonic multiagent architecture under development.

Grid-tied PV integrated boost inverter

Faculty involved: *Behrooz Mirafzal*

Power converters in PV systems convert the low voltage DC output of PV panels to AC form at the proper voltage level and frequency. None of the existing topologies encompasses a single-stage topology that satisfies these features. They either use a two-stage conversion topology with a boost circuit as the first stage—to step-up the low output voltage of the PV panel to a proper level for inverting—and an inverter at the second stage—to convert the stepped-up DC voltage to AC form. In the case of a single-stage conversion topology, they employ an array of series-connected panels to develop a high DC voltage without using a boost circuit and an inverter to produce AC voltage. These architectures, compared with the proposed single-stage boost-inverter topology, increase the system costs and reduce the system reliability and lifetime. The cost increase arises from the design and construction of a separate DC-to-DC boost converter, with at least one more power switch and an electrolytic capacitor between the converter and inverter of the two-stage topologies, or from the need for series connection of a large number of PV panels to meet the minimum DC voltage requirements for the single-stage topologies. On the other hand, the use of electrolytic capacitors reduces the reliability and effective lifetimes of the two-stage topologies. This is because electrolytic capacitors have shorter average lifetimes than the other components in PV systems, such as PV panels, semiconductor devices and control circuit boards. The integration of these into the rest of the system will reduce the expected lifetime of the entire power system. Additionally, the employment of series components—either a DC-DC boost converter in two-stage topologies or series-connected panels in single-stage topologies—has an inevitable negative impact on the overall system efficiency and utilization.

Developing power-related lab experiences in an introductory course



Faculty involved: *Shelli Starrett*

Faculty members have researched the needed parts and components and built modules to use in a freshman laboratory. They purchased induction motors, inductor banks, AC/DC bridges and capacitor banks as parts and put together in student friendly modules. The researchers also have put together adaptors for easy and safe connection of the new modules to the existing variacs.

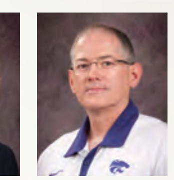
The faculty members modified the lab procedure under development to facilitate the use of the new equipment. Students working on the project tested the procedure. The procedure and new equipment modules were then used in the ECE 210 lab during the fall 2012 and spring 2013 semesters. Based on feedback from the lab teaching assistants, the procedure was modified for use in fall 2013. Some instructions were clarified and some statements added to help ensure the safety of the components.

Faculty members determined that there was a shortage of handheld power meters in the lab. They used some project funds to purchase two new meters for the lab. These meters are crucial to help students complete power-related work in the lab and the change of funding purposes was approved.

The first version of the new final project option has been written and will be implemented for fall 2013.

Westar energy, energy efficiency intern program





Faculty involved: *Bruce Snead, Nancy Larson, David Carter*

EPAP funding helped Engineering Extension hire two engineering interns to participate in the Pollution Prevention Institute's Pollution Prevention Intern Program. The institute augmented its existing intern program by focusing solely on energy demand side projects. Andrew Smith, senior in chemical engineering, worked with Omaha Public Power District in Omaha, Nebraska, to baseline energy consumption in several health care facilities and to conduct energy assessments. Mikhail Crawford, master's student in mechanical engineering, was placed at Foot Locker Services Center in Junction City, where he helped with a cost feasibility analysis to retrofit metal halide lighting to T5 fluorescent lighting or T8 fluorescent or LED lighting.

At the Omaha Public Power District, Smith used Energy STAR Portfolio Manager to benchmark 18 months of energy use data for 40 health care facilities in the district's service territory. When each building had a completed benchmark, Smith visited each site to complete information on the HVAC system and lighting use. Omaha Public Power District engineers used this information to determine available incentives for implementing energy efficiency projects. The Energy STAR energy intensity—in kBTU per square foot—for the buildings ranged from 56.3 to 242.5.

Crawford's main project involved the relamping of Foot Locker's 1.3 million-square-foot distribution center. His calculations indicated the lighting service load would be reduced as much as 65 percent by switching to T5HO fluorescent lighting, but could be reduced 85 percent using LED technology. The project, scheduled for implementation this year, is estimated to save approximately 3,000 megawatt-hours of electricity.

2013-2014 EPAP research projects

Congratulations to the following faculty for being awarded funding for the 2013-2014 academic year. Below is a short abstract of all research currently supported through the EPAP program.

Active control of wind turbine rotor shaft vibrations

Faculty involved: *Warren White*

The wind turbine gearbox is the most vulnerable part of the device and repairs are extremely expensive. The main source of these difficulties is the turbine shaft. In-plane blade vibration and changing winds produce torsional oscillations from the rotor hub through the gearbox and finally the generator. Out-of-plane blade vibrations cause the rotor shaft to bend (the same way you would snap a twig). This project seeks to limit the torsional vibrations using suitable control of the generator torque. By controlling the blade pitch, the project seeks to limit the shaft bending. Active control of vibrations is the most cost-effective tool for turbine life extension.

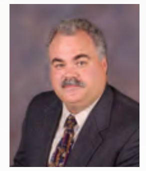
Coordinated EV charging from a techno-economic perspective



Faculty involved: *Bala Natarajan, Anil Pahwa, Larry Erickson*

Thanks to their environmental, social and economic benefits, electric vehicles, or EVs, are expected to become a major component of the power grid. Studies have illustrated the inability of the current distribution system to accommodate a high penetration of EVs. The question that we seek to address in this research effort is the following: How can we manage/control in a coordinated manner both EV charging as well as non-EV loads, renewable energy based distributed generators to best maintain grid stability and reliability while maximizing the payoffs for the stakeholders?The results and findings from our work will help grid operators to evaluate and plan future investments related to both EV charging stations as well as distributed generation.

Enhanced power plant cooling to reduce water withdrawal and consumption

Faculty involved: *Amy Betz and Steve Eckles*

In this work, we are investigating enhanced condensation in water systems using microstructured surfaces. We expect microstructured surfaces to increase condensation heat transfer due to their increased surface area, potential to thin the liquid film at the surface, increased convection in the liquid film, and increased drop-wise condensation. By enhancing condensation we can lower the output temperature of a turbine and increase the overall thermal efficiency of a cycle and decrease the condenser load. This research will be conducted by undergraduate students and the test setup will be used in courses in the mechanical engineering department.

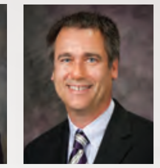
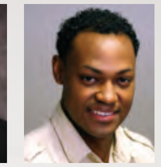
Improving quality of power plant wastewater using constructed wetland systems



Faculty involved: *Natalie Mladenov, Ganga Hettiarachchi, Stacy Hutchinson*

Toxic trace elements, such as selenium, arsenic and mercury, are routinely removed from the air emissions of coal-fired power plants using flue-gas-desulfurization (FGD) technology. Toxic trace elements and other pollutants ultimately become concentrated in FGD wastewater discharge and pose a threat to water quality. The research proposed will evaluate the sequestration of toxic trace elements using constructed wetlands. The performance of native Kansas soil and soil amended with biochar and biosolids will be assessed. Field visits to Jeffrey Energy Center will be incorporated into the PIs' graduate-level wastewater and soil chemistry courses.

Smart grid networking protocols design and implementation in GENI

Faculty involved: *Caterina Scoglio, Don Gruenbacher, Ali Sydney*

The smart grid concept includes the application of advanced networking and power technologies to obtain a highly automated, responsive and resilient transmission and distribution infrastructure. This project develops smart grid networking solutions through rigorous analysis and experimentation in the real-world environment and on the national scale that incorporates the smart grid resources from the Smart Grid Lab at K-State, and networking resources of both K-State and the GENI (Global Environment for Network Innovations) testbeds. The objectives for this work are subdivided into three phases:

1. Develop protocols and algorithms to communicate among components of the power grid considering characteristics and requirements of generated traffic.
2. Develop mathematical models to evaluate and optimize the performance of the proposed protocols.
3. Implement the proposed protocols and algorithms in a simulation environment, and deploy working prototypes within the K-State Smart Grid Lab and GENI.

Support for the 2013 North American Power Symposium at Kansas State University, Manhattan, Sept. 22-24, 2013

Faculty involved: *Anil Pahwa*

This symposium is a forum where students and their professors can present and publish research ideas and results with a minimum time delay. The conference format is designed to promote interaction among established leaders from academia and industry representing a wide range of expertise in energy and power systems, postdoctoral scientists and graduate students. This allows NAPS participants to contribute and advance the state of the art toward a safer and more reliable power grid. EPAP's financial support for activities related to the conference will help greatly in achieving this goal.

List of students participating in projects

Fariba Fetah, Graduate Ph.D., Electrical Engineering, working with Warren White, "Active Control of Wind Turbine Rotor Shaft Vibrations."

Zhichao Yu, Graduate Master's, Mechanical Engineering, working with Warren White, "Active Control of Wind Turbine Rotor Shaft Vibrations."

Andres Martinez, Senior, Mechanical Engineering, working with Amy Betz, "Enhanced Cooling to Reduce Water Withdrawal and Consumption in Power Generation."

Caleb Chiroy, Senior, Mechanical Engineering, working with Amy Betz, "Enhanced Cooling to Reduce Water Withdrawal and Consumption in Power Generation."

Kumarsinh Jhala, Graduate Master's, Electrical Engineering, working with Bala Natarajan, "Coordinated EV Charging from a Techno-Economic Perspective."

Jose Paredez, Graduate Master's, Civil Engineering, working with Natalie Mladenov, "Improving the quality of power plant wastewater using constructed wetland systems."

Madhubhashnin Galkaduwa, Graduate Ph.D., Agronomy, working with Natalie Mladenov, "Improving the quality of power plant wastewater using constructed wetland systems."

Carmen Borau Ramos, Senior, Civil Engineering, working with Natalie Mladenov, "Improving the quality of power plant wastewater using constructed wetland systems."

Adam Marshall, Senior, Chemistry at University of Florida, working with Natalie Mladenov, "Improving the quality of power plant wastewater using constructed wetland systems."


ELECTRICAL POWER AFFILIATES PROGRAM

Kansas State University
College of Engineering
Department of Electrical and Computer Engineering
2061 Rathbone Hall
Manhattan, KS 66506-5201
440

Nonprofit Organization
U.S. POSTAGE
PAID
Permit #525
Manhattan, KS 66502

Executive Sponsors

Burns & McDonnell
KCP&L
OPPD Omaha Public Power District
Westar Energy

Member Sponsors

fishnet Security
Sega Engineering & Technical Services
SEL Schweitzer Engineering Laboratories
KEC Kansas Electric Cooperatives, Inc.

Kansas State University