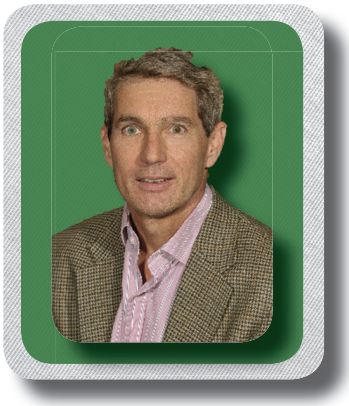
CURENT

Newsletter

Fall 2014 | Issue 3

Dr. Fred Wang, CURENT's Technical Director, demonstrates the center's Hardware Testbed

a National Science Foundation & Department of Energy Engineering Research Center



from the Director

Dr. Kevin Tomsovic

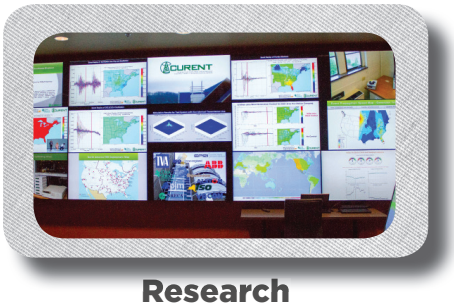
As the summer begins to wind down and we look towards the fall, it's time once again to update you about what we've been working on here at CURENT.

Since our last newsletter, we have successfully wrapped up our third annual Industry Conference and Site Visit. I'm happy to say that CURENT has been recommended for continued funding following our renewal-year review by the National Science Foundation & Department of Energy. Not only have we seen growth in our membership, we have seen significant progress in our education programs, our innovation ecosystem and research activities. We were able to demonstrate our closed loop wide area voltage control and frequency control approaches on engineering platforms, the Hardware Test-Bed and Large-Scale Test-bed. Also, we initiated a Data architecture and data analytics project which complements the vision and goals of CURENT.

As we finish up our Generation 1 efforts, we're looking forward to working closely with you on the next generation of developments at CURENT, and we thank you for your continued support.

Best Wishes,

in this issue



A Fast and Robust Linear State Estimator Using Synchronized Phasor Measurements

Despite being widely used, the weighted least squares (WLS) estimator remains to be non-robust, i.e. estimated states will be inaccurate or grossly biased in the presence of bad measurements. A more robust and computationally competitive alternative estimator called the least absolute value (LAV) estimator was investigated. A LAV based "phasor-only" state estimator was developed which has some very unique advantages when compared to the traditional WLS estimator. This approach is statistically robust since it will automatically reject gross measurements, eliminate their impact on the estimated state and it is also computationally efficient due to the linearity of the phasor measurement equations.

The developed estimator was tested using a 3625-bus utility power system, which is measured by only phasor measurements. The voltage and current phasors are measured at 3800 branches to ensure that the system is observable and has redundancy in the measurements. Gaussian errors were intentionally added to all measurements to simulate noisy measurements as would be the case in an actual EMS environment.

Among the many cases tested, three representative cases where there exists (a) no bad data; (b) single bad data; and (3) five bad data, will be presented. In cases (b) and (c), 100 runs were performed, and errors were introduced to both voltage and current phasor measurements. Mean squared error (MSE) is computed as shown below:

$$MSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i^{estimated} - x_i^{true})^2}$$

The table below provides a comparison of the computational performance of the two estimators for the above three cases using the average cpu times of the 100 simulations for each case. Simulation CPU times include the sum of state estimation solution plus bad data processing times for the WLS estimator and the overall solution time for the LAV estimator. Note the increase in total processing time for the WLS estimator with an increasing number of bad data versus the relatively fixed computation time for the LAV estimator which successfully rejected bad data for all cases. While the actual CPU times naturally will depend on the processor speed and implementation details (here sparse matrix methods are employed, but no effort is put towards code optimization and simulations are carried out on a commonly used laptop computer), the trend will remain valid irrespective of these factors.

3625-Bus Utility System Simulation Results

Estimator	Case Number					
	2.a		2.b		2.c	
	CPU (second)	MSE ($x10^{-3}$)	CPU (second)	MSE ($x10^{-3}$)	CPU (second)	MSE ($x10^{-3}$)
LAV	3.33	0.74	4.80	0.77	4.74	1.4
WLS	2.32	0.73	9.31	0.95	15.81	2.9

faculty spotlight

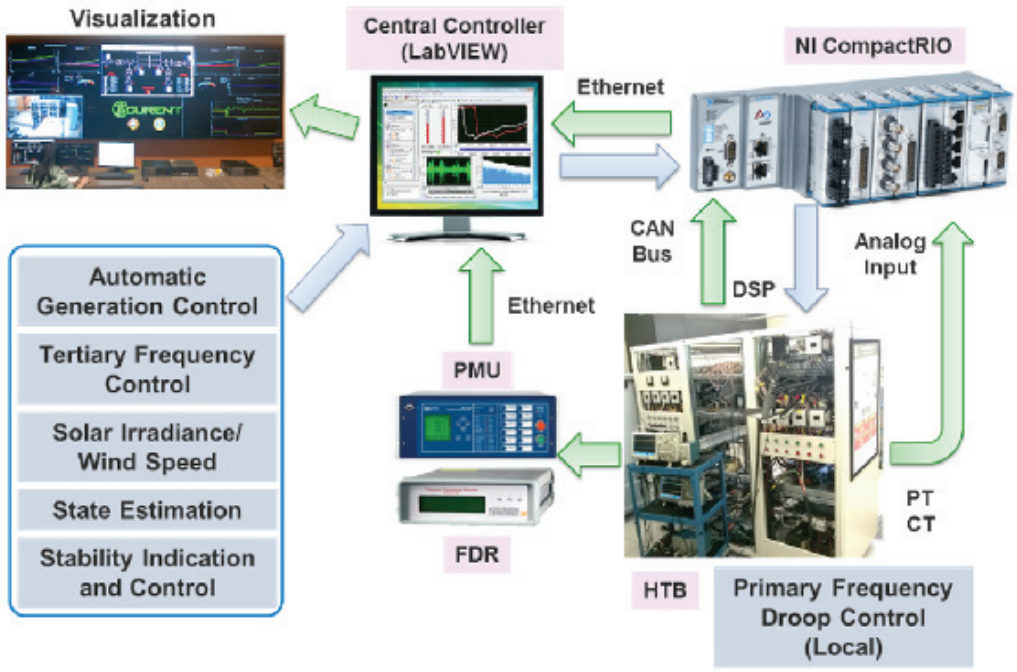
Dr. Hector A. Pulgar recently joined CURENT's research group and the University of Tennessee as an Assistant Professor. He earned his Ph.D. in Electrical Engineering from the University of Illinois at Urbana-Champaign in 2010.

Dr. Pulgar's research interests include power system dynamics & stability, power system operation & control, and renewable energy integration.

Welcome, Dr. Pulgar!

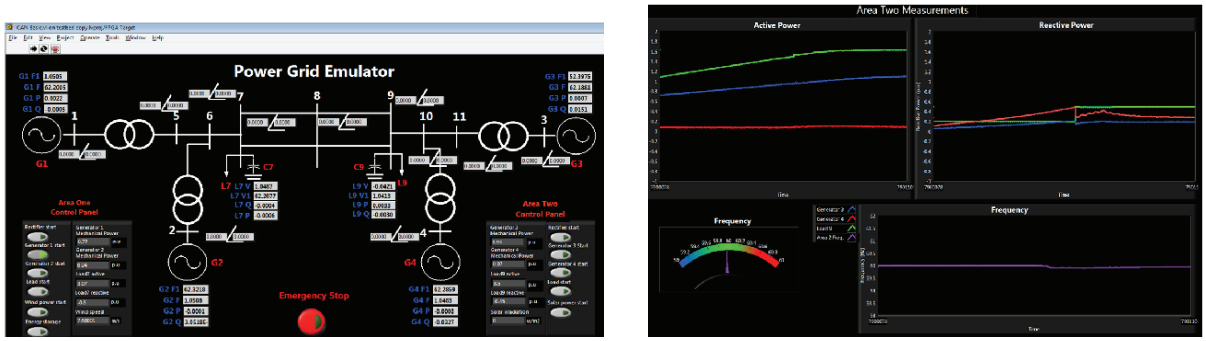
Hardware Testbed

The control and visualization room has been built in the HTB to mimic a real control center in the industry. Phasor measurement units (PMUs), frequency disturbance recorders (FDRs), potential transformers (PTs), and current transformers (CTs) are installed at various buses to monitor the power flow, voltage amplitude and angle independently. Signals from the above devices are directly or indirectly delivered to the computer through Ethernet. Then, the measurement data will be updated and displayed on the visualization wall every 0.1 s.



Hardware Testbed Communication Structure

The control center utilizes the LabVIEW platform. It is capable of sending supervisory control commands, such as power dispatch, wind speed, and irradiance level to the emulators. Generation references calculated by AGC are sent to the generator emulators in the HTB through CAN bus. In addition to the traditional method, AGC can be also realized through state estimation or other improved methods in LabVIEW.



Hardware Testbed Control Panel & Measurement Display

In addition to the construction of the control center, ongoing work has been carried out for developing new emulators. Flywheel energy storage emulator has been tested in the HTB with different scenarios; transmission line emulator with a back-to-back structure is now installed in the HTB and under test; preliminary experiments on RTDS hardware-in-the-loop simulation has been performed. Furthermore, the 3rd cabinet has been built and tested in the HTB.

Based on the above efforts, the HTB is now aiming at expanding to a 3 or 4 area system, and involving testing scenarios with more renewable energy sources, HVDC and many other advanced technologies.

A Synchrophasor Measurement Based Method for Assessing Damping Torque Contributions from Power System Stabilizers

Damping torques for power system swing modes are typically provided by power system stabilizers (PSSs) acting through voltage regulation of generators. In particular, inter-area mode damping contributions normally come from many generators. It is not trivial to check whether a PSS is providing positive damping contribution in a power system simulation program, let alone using field tests or measured data from generator testing.

At CURENT we are developing a damping torque assessment method based on synchronized measurements of the generator rotor angle and its terminal bus voltage phasor, as an extension of the deMello-Concordia synchronizing and damping torque decomposition. The method involves extracting the modal components from the measurements and comparing the phases of these components.

The linearized block diagram for the local mode of a single-machine infinite-bus (SMIB) system is shown below. It is important to note that the Δ quantities in the diagram are the local mode components of the measured quantities.

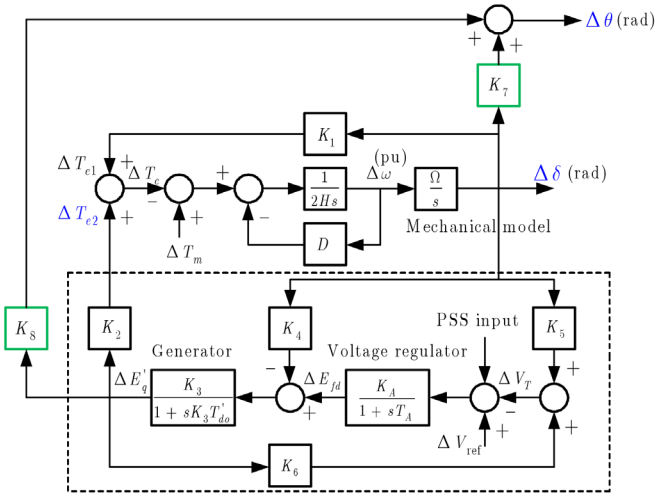


Figure 1 - SMIB block diagram

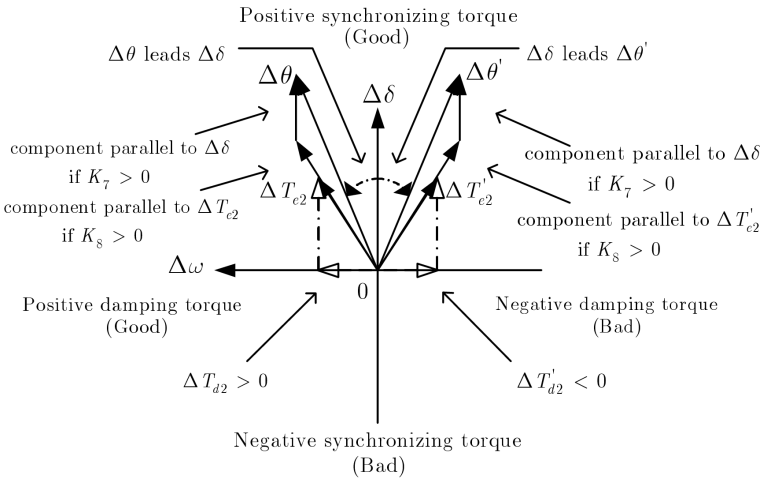


Figure 2 - SMIB local mode phasor relationship diagram

The quantity of interest is the electrical torque (ΔT_{e2}) from the generator internals. ΔT_{e2} can be decomposed into $\Delta T_{e2}=\Delta T_{s2}+j\Delta T_{d2}$ where ΔT_{s2} is the synchronizing torque in the direction of $\Delta\delta$ and ΔT_{d2} is the damping torque in the direction of $\Delta\omega$. From Figure 1, we see that ΔT_{e2} is in the direction of $\Delta E'_q$ but it is difficult to measure T_{e2} or E'_q directly. Instead, we note that the terminal bus angle θ is mainly dependent on the rotor angle δ and E'_q and therefore we can develop the relationships as shown in the phasor diagram in Figure 2. As can be seen, we only need to examine the phase difference between $\Delta\theta$ and $\Delta\delta$. A generator with a working PSS providing positive ΔT_{d2} is indicated by $\Delta\theta$ having a noticeable phase lead over $\Delta\delta$. If the $\Delta\theta$-$\Delta\delta$ phase difference is small or negative, then the generator and its PSS settings should be examined.

The new assessment method can be extended to inter-area modes within multi-machine systems. The method has been tested on both the SMIB system and a multi-machine system using both linear analysis and non-linear simulations, and the results have been consistent with the theoretical predictions.

This method can be applied if unstable or lightly damped oscillations are observed on a power system after major disturbances, without the need to do specific generator testing. Only synchronized measurements of δ and θ are needed. The method can also be applied to time responses from simulation programs. Thus for inter-area modes, this method is useful in determining which PSSs are providing damping torque and which PSSs are not.

Student spotlight

Jing Xue, a Ph.D. candidate in CURENT, recently spent three months interning at Rockwell Automation. Jing served as an Electrical Engineer Intern, and assisted in the design of EMI filters and capacitors for high-powered motor drives.

Rockwell Automation

Summer Church, a sophomore in electrical engineering, interned during the summer at Johnson City Power Board.

Summer has also participated in research, outreach, and was an Ambassador with CURENT during the 2013-2014 school year.

Hayden Dahmm, a junior at Swarthmore College, participated in the 2014 Research Experience for Undergraduates (REU).

Hayden has intersts in renewable energy and engineering. Pictured is Hayden and his guide dog, Fathom.

May Mahmoudi won 2nd Place at the 2014 IEEE Power and Energy Systems poster contest.

Her poster was entitled: **Distributed Control Schemes for Damping Inter-area Oscillations**

Derek Kou is the 2014-2015 Student Leadership Council President. Derek was previously the External Vice President.

Ikponmwosa Idehen won best paper at the NSF 2014 Site Visit Industry Day. His paper was entitled: A Method for Distributed Control of Reactive Power and Voltage in a Power Grid: A Game Theoretic Approach.

Congratulations to the recent graduates within the center. the following students completed their sutdies at CURENT in Spring 2014:

- **Lily Hoang**, BS, ENERCON Services
- **Elisa Cheng**, MS, Jacobs Engineering
- **Ikponmwosa Idehen**, MS, University of Illinois
- **Bailu Xiao**, Post-Doc Researcher, ORNL
- **Zhibo Wang**, Post-Doc Researcher, Wahan University

Other Recent Internships

Mwamba Bowa	ORNL/MDF
Saajid Haque	Alcoa
Mathew Lambert	EPRI
Stephanie Steren-Ruta	Southern Company
Micah Till	Dominion Virginia Power
Linquan Bai	ABB
Ben Guo	ABB & United Technologies
Kumaraguru Prabakar	Ford Motor
Ling Wu	Dominion Virginia Power
Yao Xu	Enernex
Maryam Hassan Variani	ERCOT

IEEE Power & Energy Society General Meeting, July 27-31, 2014

CURENT teams up with ORNL to win R&D100 Award

ORNL in partnership with SPX Transformer Solutions Inc. and the University of Tennessee have developed the Continuously Variable Series Reactor (CVSR), which recently won the prestigious R&D100 Award.

The CVSR is a high power magnetic amplifier that controls power flow in power systems. In operation, where conditions constantly change, a single CVSR will provide smoothly variable alternating current circuit impedance, while a number of coordinated CVSR's installed throughout the power system can provide full power system control. CVSR's unique design helps to ensure full use of power system assets, increased reliability and efficiency and effective use of renewable resources.

The research is funded by DOE's Advanced Research Project Agency-Energy under the Green Electricity Network Integration program. The technology was developed by Dr. Aleksander Dimitrovski and Dr. Burak Ozpineci. Dr. Kevin Tomsoic and Dr. Yilu Liu are part of the award wiinning team from CURENT.

Congratulations Faculty

At the 2014 IEEE Power and Energy Systems General Meeting, several CURENT faculty were recognized for their contributions.

IEEE PES Charles Concordia Power Systems Engineering Award

Joe Hong Chow

For the development of analysis techniques and innovative control and measurement systems to improve power system performance and reliability

IEEE PES Outstanding Power Engineering Educator Award

Ali Abur

For contributions to the instructional computer-based tools and methods for teaching power system state estimation

Kevin Tomsovic also received a Distinguished Service Award

summer happenings

CURENT's Annual Conference

2014 INDUSTRY CONFERENCE & SITE VISIT

CURENT recently hosted nearly 200 people in Knoxville for the center's 2014 Industry Conference & NSF/DOE Site Visit.

The event covered five days and brought together industry affiliates, academic experts, and federal agency representatives to discuss the research progress and direction in the center. The Industry Conference portion provided CURENT's member companies and other interested industry affiliates with the opportunity to interact with the center's faculty and students. Additionally, the Site Visit brought program managers and a "Site Visit Team" from the National Science Foundation and the Department of Energy to review progress and offer suggestions on future research.

Plenary guest speakers came from ABB, EPRI, Google, and NY-ISO, and dual sessions in both power systems and power electronics provided attendees with a wide variety of ongoing projects at CURENT. Attendees also toured the center's labs and took part in a demo of CURENT's recently-completed hardware testbed, which allows testing of various power system architectures and provides demonstrations of monitoring, control, actuation and visualization technologies.

2014 was also a funding renewal year for CURENT, and NSF & DOE Site Visit Team recently recommended the center for renewal funding through 2016 following the Industry Conference & Site Visit.

Welcome to Our Newest Industry Partners!

NATIONAL INSTRUMENTS

HUAWEI

SOUTHERN COMPANY
Energy to Serve Your World℠

NREL

Adventures in STEM for Girls

Twenty-five middle school girls spent a week this summer at CURENT for the center's Adventures in STEM summer camp.

The camp gives girls the opportunity to explore a variety of STEM fields, including electrical engineering, biology, and math. This year, the girls designed a small-scale transmission grid, worked with 3-D printers, and took a field trip to ORNL's Advanced Manufacturing Lab and the American Museum of Science and Energy.

Some students traveled from over 100 miles away to Knoxville, making the third year of Adventures in STEM its most successful rendition yet!

Research Experience Highlights

On July 18th, CURENT wrapped up its summer research programs with a poster symposium that displayed the work of 18 high school students, 3 middle school teachers, 3 high school teachers, and 14 undergraduate students.

The undergraduate students represented universities from across the country including Auburn, Georgia Tech, RPI, Swarthmore College, University of North Carolina, University of Oklahoma, University of Puerto Rico, and Washington State University.

ERC Program Bi-Annual Meeting

October 26th - 28th, 2014

- Hyatt Regency Crystal City
- Arlington, Virginia
- 8:00 AM to 5:00 PM EST

For More Information

- www.nsferc2014.com

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CENTER FOR ULTRA-WIDE-AREA RESILIENT ELECTRIC ENERGY TRANSMISSION NETWORKS

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