

Title: Smart Grid Research Center Energy Research Initiative

Duration: 2010-2013

Sponsor: Semiconductor Research Corporation (SRC)

Contributing Faculty: Marija Ilic, Gabriela Hug, Franz Franchetti

Contributing Students: Jhi-Young Joo, Andrew Hsu, Nipun Popli, Qixing Lui, Milos Cvetkovic, Sanja Cvijic, Rui Yang, Tao Cui, Kevin Bachovchin,

Description: The mission of the Carnegie Mellon Smart Grid Research Center (SGRC) was to develop an Information Communications Technology (ICT)-enabled framework for Dynamic Monitoring and Decision Systems (DYMONDS) in support of a sustainable evolution and re-engineering of today's electric power system into future generations of energy systems. These next generation systems will be capable of meeting dynamically evolving complex tradeoffs between economics and societal and energy service user needs in both the short-term and very long-term. The ICT-enabled tools will support flexible on-line interactions across the industry according to two fundamental principles: (P1) Enabling sufficient autonomy to the particular (groups of) stakeholders to pursue their own objectives while taking into consideration interactions with the others; and, (P2) Utilizing the output based on the decision making by the particular (groups of) stakeholders for effective aggregation and management of larger (groups of) stakeholders toward achieving goals of interest to these larger groups, and, ultimately, to the system as a whole.

Individual Tasks:

Task 2111.001: Adaptive Load Management (ALM)

Student: Jhi-Young Joo

Principal Investigator: Marija Ilic

This research develops an economic model (software simulation/tools) and decision making strategies (algorithms and software implementation) for load aggregators which comprehend uncertainty in supply/demand and incorporate adaptive load management.

Task 2111.002: Dynamics and Control of Smart Grids: Combined Effects of Phasor Measurement Units (PMUs), Dynamic Line Rating Units (DLRs) and System Dispatch

Student: Andrew Hsu, Nipun Popli, Qixing Lui

Principal Investigator: Marija Ilic

This research introduces novel concepts for modeling system dynamics driven by novel dispatch supported by fast and accurate measurements and sensors. The emphasis is on understanding the dynamics and control needed for ensuring that such systems do not experience instability.

Task 2111.003: Nonlinear Control of Flexible AC Transmission Systems (FACTS) for Transient Stabilization

Student: Milos Cvetkovic

Principal Investigator: Marija Ilic

This research demonstrates use of nonlinear control of Flexible AC Transmission Systems (FACTS) to transiently stabilize the response of complex power networks during major equipment failures.

Task 2111.004: Pushing the Limits to Computing: Managing Resources in a Reliable and Efficient Way in Large-Scale Electric Power Grids

Student: Sanja Cvijic

Principal Investigator: Marija Ilic

This research introduces a new computational framework to managing energy resources in which inter-temporal and inter-spatial dependencies are critical for both making the system reliable and efficient.

Task 2111.005: Optimal Usage of Transmission Capacity using Power Flow Control Devices

Student: Rui Yang

Principal Investigator: Gabriela Hug

This research provides methods for using existing transmission system capacity in a more flexible and optimized way to enable integration of significant variable energy generation resources.

Task 2111.006: Smart Grid Privacy Through Secure Multiparty Computation

Student: Tao Cui

Principal Investigator: Franz Franchetti

This research investigates the applicability of secure multi-party computation as a fundamental tool for preserving the privacy of smart grid users.

Task 2111.007: Modeling and Control for Efficient and Stable Integration of Flywheels and Other Fast Storage in Future Electric Energy Systems

Student: Kevin Bachovchin

Principal Investigator: Marija Ilic

This research explores the integration of flywheel energy storage systems in power grids for fast time-scale applications, such as frequency stabilization in response to large wind disturbances. Flywheels can respond faster than conventional generators and could stabilize the system in response to a large disturbance until slower generators can respond. Also using flywheels for transient stabilize could have an economic benefit by reducing the wear-and-tear on generators. Power system dynamic models are derived in an automated manner using the Lagrangian formulation from classical mechanics. Non-linear power electronic control of flywheels is designed using sliding mode control and energy based control.

List of Publications:

Cory Thoma, Tao Cui, Franz Franchetti, "Privacy Preserving Smart Metering System Based Retail Level Electricity Market," The PES General Meeting, Vancouver BC, Canada, 2013.

Cory Thoma, Tao Cui, Franz Franchetti, "Secure Multiparty Computation Based Privacy Preserving Smart Metering System," The 44th North American Power Symposium (NAPS), Urbana IL, 2012

Ilic, M. and Hsu, A. "Toward Distributed Contingency Screening Using Line Flow Calculators and Dynamic Line Rating Units (DLRs)", Hawaiian International Conference of System Sciences (HICSS). Maui, Hawaii, January 2012.

Hsu, A. and Ilic, M. "Distributed Newton Method For Computing Real Decoupled Power Flow In Lossy Electric Energy Networks", North American Power Symposium (NAPS), 2012, vol., no., pp.1-7, 9-11 Sept. 2012.

Ilic, M. and Hsu, A. "General Method For Distributed Line Flow Computing With Local Communications In Meshed Electric Networks", Patent application 20130024168, January 5, 2013

Ilic, M. and Hsu, A. "Ensuring Feasible Power Delivery Using An Optimization Based Power Flow Model," Techcon 2013, Austin TX, September 2013.

Sanja Cvijić, Jinjun Xiong, "Security Constrained Unit Commitment and Economic Dispatch through Benders Decomposition: A Comparative Study", IEEE PES General Meeting, Detroit, USA, July 2011.

Sanja Cvijić, Marija Ilić, "On Limits to the Graph-Theoretic Approaches in the Electric Power Systems", 43rd NAPS, Boston, USA, Aug 2011, second prize for the best paper and presentation

Sanja Cvijić, Marija Ilić, "Contingency Screening in a Multi-Control Area System Using Coordinated DC Power Flow", ISGT Europe 2011, Manchester, December 2011

Sanja Cvijic, Peter Feldmann and Marija Ilic, "Applications of Homotopy for Solving AC Power Flow and AC Optimal Power Flow", PES General Meeting in San Diego, July 2012

Sanja Cvijic and Marija Ilic, "Optimal Clustering for Efficient Computations of Contingency Effects in Large Regional Power Systems", PES General Meeting in San Diego, July 2012

Sanja Cvijic and Marija Ilic, "Decentralized Reduction of Wheeling Loop Flows in Regional Power Networks", ISGT Europe 2012, Berlin, Germany

Sanja Cvijic, Milos Cvetkovic, Marija Ilic, "A Graph-theoretic Approach to Modeling Network Effects of Phase Shifters on Active Power Loop Flows", NAPS, Urbana-Champaign, IL, September 2012

Sanja Cvijic, Marija Ilic, "Distributed Multiparty DC Power Flow Algorithm with Secure Exchange of Information", Lecture Notes on Control and Information Sciences, Springer

Sanja Cvijic, Marija Ilic, "Part I: A New Framework for Modeling and Tracing of Bilateral Transactions and the Corresponding Loop Flows in Multi-Control Area Power Networks", submitted to IEEE Transactions on Power Systems

Sanja Cvijic, Marija Ilic, "Part II: PAR Flow Control Based on the Framework for Modeling and Tracing of Bilateral Transactions and Corresponding Loop Flows", submitted to IEEE Transactions on Power Systems

Marija Ilić, Nipun Popli, Jhi-Young Joo, and Yunhe Hou, "A Possible Engineering and Economic Framework for Implementing Demand Side Participation in Frequency Regulation at Value," IEEE Power and Energy Society General Meeting, July 2011

Sérgio Pequito, Clarence Agbi, Nipun Popli, Soumya Kar, A. Pedro Aguiar and Marija Ilic, Designing Decentralized Control Systems without Structural Fixed Modes: A Multilayer Approach, To appear in NecSys'13

Nipun Popli, Marija Ilić, "Multi Input Multi Output (MIMO) Tracking of Power Imbalances in Wind Penetrated Electric Power Grids", Submitted to TECHON-2013, SRC

Sérgio Pequito, Nipun Popli, Soumya Kar, Marija D. Ilic and A. Pedro Aguiar, A Framework for Actuator Placement in Large Scale Power Systems: Minimal Strong Structural Controllability, Submitted to the Fifth IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing

L. Xie, P. M. S. Carvalho, L. A. F. M. Ferreira, J. Liu, B. Krogh, N. Popli, and M. D. Ilic, "Wind energy integration in power systems: operational challenges and possible solutions," Proceedings of IEEE: Special Issue on Network Systems Engineering for Meeting the Energy and Environment Dream (Invited). Vol. 99, No. 1, pp. 214 -232, January 2011

N. Popli, M. Ilic, Modeling & Control Framework to Ensure Intra-Dispatch Regulation Reserves, Chapter-14, March 2012, Engineering IT-Enabled Sustainable Electricity Services: The Tale of Two Low-Cost Green Azores Islands

Jhi-Young Joo, Jonathan Donadee, and Marija Ilić, "Assessing the Ability of Different Types of Loads to Participate in Adaptive Load Management," *Engineering IT-Enabled Electricity Services; The Tale Of Two Low-Cost Green Azores Islands*, Ed. Marija Ilić, Le Xie, and Qixing Liu, Springer, August 2013

Jhi-Young Joo, Yingzhong Gu, Le Xie, Jonathan Donadee, and Marija Ilić, "Look-ahead Model-Predictive Coordinated Generation and Demand Dispatch Methods for Managing Uncertainties," *Engineering IT-Enabled Electricity Services; The Tale Of Two Low-Cost Green Azores Islands*, Ed. Marija Ilić, Le Xie, and Qixing Liu, Springer, August 2013

Jonathan Donadee, Jhi-Young Joo, Remco Verzijlbergh, and Marija Ilić, "Generation and Demand Characteristics of the Islands of Flores and São Miguel," *Engineering IT-Enabled Electricity Services; The Tale Of Two Low-Cost Green Azores Islands*, Ed. Marija Ilić, Le Xie,

and Qixing Liu, Springer, August 2013

Jhi-Young Joo, and Marija Ilić, "Multi-Layered Optimization Of Demand Resources Using Lagrange Dual Decomposition," *IEEE Transactions On Smart Grid*, Special Issue on Real-Time Demand Response, *accepted for publication in April 2013*

Marija Ilić, Jhi-Young Joo, Le Xie, Marija Prica, and Niklas Rotering, "A Decision Making Framework and Simulator for Sustainable Electric Energy Systems," *IEEE Transactions on Sustainable Energy*, Volume 2, Issue 1, January 2011

Marija Ilić, Le Xie, and Jhi-Young Joo, "Efficient Coordination of Wind Power and Price-Responsive Demand, Part I: Theoretical Foundations," *IEEE Transactions on Power Systems*, Volume 26, Issue 4, November 2011

Marija Ilić, Le Xie, and Jhi-Young Joo, "Efficient Coordination of Wind Power and Price-Responsive Demand, Part II: Case Studies," *IEEE Transactions on Sustainable Energy*, Volume 26, Issue 4, November 2011

Marija Ilić, Jhi-Young Joo, Pedro M.S. Carvalho, Luís A.F.M. Ferreira, and Bernardo Almeida, "Dynamic Monitoring and Decision Systems (DYMONDS) Framework for Reliable and Efficient Congestion Management in Smart Distribution Grids," *Bulk Power System Dynamics and Control, iREP Symposium*, August 2013

Jhi-Young Joo, and Marija Ilić, "Distributed Multi-Temporal Risk Management Approach to Designing Dynamic Pricing," *IEEE Power and Energy Society General Meeting*, July 2012

Jhi-Young Joo, and Marija Ilić, "Multi-Temporal Risk Minimization Of Adaptive Load Management In Electricity Spot Markets," *IEEE Power and Energy Society Innovative Smart Grid Technologies Europe*, December 2011

Jhi-Young Joo, and Marija Ilić, "A Multi-Layered Adaptive Load Management (ALM) System: Information exchange between market participants for efficient and reliable energy use," *2010 IEEE Power and Energy Society Transmission and Distribution Conference*, April 2010

Jhi-Young Joo, and Marija Ilić, "Adaptive Load Management (ALM) in Electric Power Systems," *2010 IEEE International Conference on Networking, Sensing and Control*, April 2010

Le Xie, Jhi-Young Joo, and Marija Ilić, "Integration of Intermittent Resources with Price-Responsive Loads," *2009 North American Power Symposium*, October 2009

Rui Yang, Gabriela Hug-Glanzmann, "Optimal Usage of Transmission Capacity with FACTS Devices in the Presence of Wind Generation: A Two-stage Approach," *IEEE Power and Energy Society General Meeting*, San Diego, CA, July 2012.

Rui Yang, Gabriela Hug-Glanzmann, "Regression-Based FACTS Control for Optimal Usage of Transmission Capacity," *SRC TECHCON*, Austin, TX, September 2012.

Rui Yang, Gabriela Hug-Glanzmann, "Regression-Based Corrective Power Flow Control for System Risk Minimization," *IEEE Power and Energy Society General Meeting*, Vancouver, BC, Canada, July 2013.

Rui Yang, Gabriela Hug, "Locational Security Impact Factors for Security Index Constrained Economic Dispatch Problem," *45th North American Power Symposium*, Manhattan, KS, September 2013.

Rui Yang, Gabriela Hug-Glanzmann, "Regression-Based FACTS Control for Optimal Usage of Transmission Capacity," *IET Generation, Transmission and Distribution*. (Under Review)

Rui Yang, Gabriela Hug, "Potential and Efficient Computation of Corrective Power Flow Control in Cost vs. Risk Trade-Off," *IEEE Transactions on Smart Grid, Special Issue on Control Theory and Technology*. (Under Review)

M. Cvetkovic, M. Ilic, "Entropy-based Nonlinear Control of FACTS for Transient Stabilization", *IEEE Transactions on Power Systems*, to be submitted 2013.

M. Cvetkovic, M. Ilic, "Interaction Variable-based Cooperative Nonlinear Stabilization of Interconnected Power Systems", *IEEE Transactions on Power Systems*, to be submitted 2013.

M. Cvetkovic, M. Ilic, "Design of FACTS Controllers to Meet Specifications for the Interconnected Power System Stability", *IEEE Transactions on Power Systems*, to be submitted 2013.

M. Ilic, M. Cvetkovic, K. Bachovchin, Q. Liu, "Modeling, Analysis and Control Design Complexities in Future Electric Energy Systems", 15th International IEEE Power Electronics and Motion Control Conference and Exposition, Novi Sad, Serbia, September 2012.

M. Cvetkovic, M. Ilic, "Energy-Based Transient Stabilization Using FACTS in Systems With Wind Power", *IEEE Power & Energy Society General Meeting*, San Diego, CA, July 2012.

M. Cvetkovic, M. Ilic, "Nonlinear Control for Stabilizing Power Systems During Major Disturbances", *International Federation of Automatic Control World Congress*, Milan, Italy, September 2011.

M. Ilic, M. Cvetkovic, K. Bachovchin, A. Hsu, "Toward a Systems Approach to Power-Electronically Switched T&D Equipment at Value", *IEEE Power & Energy Society General Meeting*, Detroit, MI, July 2011.

M. Cvetkovic, M. Ilic, "PMU Based Transient Stabilization Using FACTS", *IEEE Power System Conference and Exposition*, Phoenix, AZ, March 2011.

M. Cvetkovic, K. Bachovchin, M. Ilic, “*Transient Stabilization in Systems with Wind Power*”, Chapter 19 in "Engineering IT Enabled Electricity Services: The Case of Low Cost Green Azures Islands", Springer, 2013.

Kevin D. Bachovchin, and Marija D. Ilić, “Automated Modeling of Electric Circuit Dynamics Using the Lagrangian and Hamiltonian Formulations” [submitted to *International Journal of Circuit Theory and Applications*]

Kevin D. Bachovchin, and Marija D. Ilić, “Automated Modeling of Power System Dynamics Using the Lagrangian Formulation” [submitted to *International Transactions on Electrical Energy Systems*]

Kevin D. Bachovchin, Milos Cvetkovic, and Marija D. Ilić, “Modular Automated Modeling of Power Systems for Obtaining Dynamic Models Including Hamiltonian Dynamics” [to be submitted]

Q. Liu, M. Cvetkovic, M. Ilic, “*Stabilization and Regulation of Small Frequency Fluctuations by Means of Governor and Flywheel Control*”, Chapter 15 in "Engineering IT Enabled Electricity Services: The Case of Low Cost Green Azures Islands", Springer, 2013.

Q. Liu, M. Cvetkovic, M. Ilic, “*Toward Stabilizing Linearized System Dynamics in Future Electric Energy Systems by Means of Enhanced Voltage Control*”, Chapter 16 in "Engineering IT Enabled Electricity Services: The Case of Low Cost Green Azures Islands", Springer, 2013.

Marija D. Ilić and Qixing Liu, “Toward Sensing, Communications and Control Architectures for Frequency Regulation in Systems with Highly Variable Resources,” Chapter 1 of Control and Optimization Methods for Electric Smart Grids, Springer, 2011.

Qixing Liu, and Marija D. Ilić, “Enhanced Automatic Generation Control (E-AGC) for Future Electric Energy Systems,” IEEE PES General Meeting, Jul 2012, San Diego, California, USA.

Marija D. Ilić and Qixing Liu, “Toward Standards for Model-Based Control of Dynamic Interactions in Large Electric Power Grids,” Asia Pacific Signal and Information Processing Association Annual Summit and Conference 2012, Dec 2012, Hollywood, California, USA.