

FLORIDA STATE UNIVERSITY *Microgrids for a Sustainable Energy Future*

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Description: To meet Florida’s renewable energy and greenhouse gas targets, there must be an aggressive sustainable energy plan. A microgrid strategy can provide a solution for meeting Florida’s sustainable energy needs. Microgrids are an amalgam of: loads; distributed generation such as: photovoltaic, wind, fuel cells and other renewable energy sources; distributed energy storage devices which include: stationary (flywheels, ultracapacitors, and batteries) and non-stationary entities such as plug-in hybrid electric and electric vehicles. Possible benefits of microgrids are:

- Reduce the number of system-wide power outages by providing islanding capabilities allowing grids to separate from each other, providing for a more stable and reliable power delivery infrastructure.
- Provide a framework in which non-traditional, low-carbon footprint, energy sources such as: wind, solar, and fuel cells can be easily integrated into the existing power system.
- Provide for intelligent energy management and increased efficiency via high-penetration levels of power electronics and control strategies.
- Provide for streamlined integration of both stationary and non-stationary energy storage devices as well as future energy conversion resources such as: ocean current and tidal.
- Directly address greenhouse gas targets.

Budget: \$719,333.00

Progress Summary

Objectives

The objectives of this proposal are listed in the following bullets:

- Provide energy consumers and policy makers with information that can positively affect their decision process.
- Provide an influx of “next generation” professionals into the governmental, academic, industrial, and utility workforce that are equipped with contemporary skills in science, engineering, economics and policy to address the complexities associated with a sustainable energy paradigm.
- Provide technological advances to aid in creating a sustainable energy future for Florida in:
 - Power electronic converter topologies for energy management, conversion, and control from distributed energy sources and storage.
 - Intelligent control methodologies/strategies for both local distributed device control and overall centralized grid coordination.
 - Utilization of combined heat and power strategies for improved microgrid efficiency.
 - Utilization of microturbines to provide grid stability and an environmentally friendly source of energy.

- Energy density of storage and generation devices such as: ultracapacitors, flywheels, and batteries.
- Metering techniques/strategies relative to a distributed energy paradigm.
- Provides funding and access to exceptional facilities for visiting summer scholars from other countries to come and share and expand their intellectual knowledge.
- Provides for an undergraduate summer fellowships to aid in recruiting highly talented senior undergraduates from across the nation.
- Provides valuable information regarding key policy and economic issues that inhibit the instantiation of microgrid strategies.
- Partially provides for symposium funding that will bring in nationally recognized researchers and key funding representatives from such agencies as: NSF, DOE, and ONR.
- Partially provides support for a workshop that will bring together state policy makers, researchers, and utility and industrial representatives to share ideas and visions, and to openly discuss critical issues in moving forward toward a sustainable energy future.
- Development of new and innovative courses that transcend the traditional boundaries engineering, policy, economics and basic science.

Scope of Work

The research efforts planned for the proposal “Microgrids for a Sustainable Energy Future” are listed as Tasks 1 ~ 7. The general purposes of these efforts are to address the research and development needs set forth by the Florida Energy Systems Consortium (FESC). Primarily, the effort will address Task 11 of FESC. Collaborative efforts are currently being planned with other FESC members. At this stage, smartgrid, smart metering, energy storage, demand response and price response research efforts by Alex Domijan and Arif Islam at the University of South Florida will be leveraged to augment the proposed FSU work.

The proposed tasks will be primarily conducted at/in the following locations:

- The Center for Advanced Power Systems.
- FAMU-FSU College of Engineering.
- FSU OGZEB in collaboration with SESEC.

2010 Annual Report

SYNERGISTIC ACTIVITIES

In Table II below is listed by PI the synergistic activities that have been associated with the opportunities that this research grant have provided. The table is intended to provide an indication of the activity and results that are currently being generated by this effort.

Investigator	Activity
Chris S. Edrington	<ol style="list-style-type: none"> 1. Brought Dr. Jost Amelling, CEO of PLEXIM to FSU to present a training seminar on PLECS as power electronics simulation package for MATLAB/Simulink. 2. Worked with the IEEE Tallahassee Area Section to provide a tour of the Hopkins power plant in the Tallahassee area. 3. Worked as a co-Chair with Dr. Tom Baldwin to bring the IEEE Industrial and Commercial Power Systems conference to Tallahassee in May 2010. 4. Acted as a session chair for the Applied Power Electronics Conference and Exposition in Palm Springs.
Helen Li	<ol style="list-style-type: none"> 1. Acted as a session chair for the Applied Power Electronics Conference and Exposition in Palm Springs in February, 2010. 2. Acted as a organizing Committee for the Proc. 2nd International Symposium on Power Electronics for Distributed Generation Systems(IEEE PEDG 2010), Hefei, China, June, 2010 3. Given a seminar to ECE Department of Missouri University of Science and Technology. 4. Invited professors from Pusan National University, Korea and Huazhong university of Science and Technology, China to visit my lab.
Juan Ordonez	<ol style="list-style-type: none"> 1. Visited the Federal University of Parana, Brazil. To participate in the development of a hybrid (fuel cell/PV/Batteries) self-sustained cabinet under AFOSR sponsorship. 2. Served as member of the International Advisory Board to the Souther Conference on Computational Modeling (Brazil).
Jim Zheng	<ol style="list-style-type: none"> 1. Treasure, Energy Technology Division of the Electrochemical Society 2. Organizer, Symposium on Catalysts for Energy Storage and Conversion, 240th American Chemical Society National Meeting & Exposition, Boston, MA, August 22-26, 2010. 3. Session chair of The 8th International Symposium on New Materials and Nano-Materials for Electrochemical Systems, Shanghai, China, July 12, 2010. 4. Editorial Advisory Board Member of The Open Electrochemistry Journal
Dave Cartes	<ol style="list-style-type: none"> 1. Organizer and host of the three symposia: <ol style="list-style-type: none"> a. Symposium on Offshore Energy Part I: Oil and Gas b. Symposium on Offshore Energy Part II: The Inshore Challenges of Offshore Energy Prospects c. Smart Mobility Part I: Opportunities for Electrified Transportation in Florida 2. Member Working Group IEEE Standard 1547.3&4 - Standard for Interconnecting Distributed Resources with Electric Power Systems

	<ol style="list-style-type: none"> 3. Control Sub-Committee Chair IEEE Standard 45-Recommended Practice for Electric Installations on Shipboard 4. Chair IEEE PES Working Group “Multi Agent Systems” 5. Member IEEE PES Task Force on 'Intelligent Control Systems' 6. Traveled to Washington DC in March to discuss an ARPA-E opportunity with Siemens and Johns Hopkins University APL. 7. Traveled to Washington DC in March to discuss and ARPA-E opportunity ARRA 2009 Smart Grid proposal to DOE OE FOA by BGE, Johns Hopkins University, and IESES/FSU. 8. Submitted DOE proposal: ILEV (Institute for Low Energy Vehicles) with Tallahassee Economic Development Council. This ILEV will start a Professional Science Master’s degree in electric vehicle and component entrepreneurship. 9. Submitted an NSF ERC Letter of Intent entitled Smart Grid – Smart Car that will integrate electric vehicle energy storage into the Smart Grid energy management scheme. 10. Site visit to Jacksonville Electric Associates. 11. Traveled to Tampa, FL for NSF – ERC Planning Meeting.
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PUBLICATIONS

In Table III, below, is a list of journal, conference and other publications that are a direct result of the efforts of this research and are meant as a measure of the effectiveness of the investigators in fulfilling the research objectives that are in the statement of work.

Table III

Article	Type
R. Bhuvanesawri, C. S. Edrington , D. A. Cartes , and S. Srikrishna, “Online Economic Environmental Optimization of a Microgrid Using an Improved Fast Evolutionary Programming Technique”, North American Power Symposium, Starkville, MS, Nov. 2009.	Conference
T. Bevis, B. Hacker, C. S. Edrington , and S. Azongha, “A Review of PHEV Grid Impacts”, North American Power Symposium, Starkville, MS, Nov. 2009.	Conference
Ramachandran, B., Srivastava, S. K., Cartes, D. , and Edrington, C. S. , “An Intelligent Auction Scheme for Smart Grid Market Using a Hybrid Immune Algorithm”, IEEE Transactions on Industrial Electronics, <i>accepted, expected publication date 2010.</i>	Journal
O. Vodyakho, C. S. Edrington , M. Steurer, S. Azongha, F. Fleming, “Synchronization of Three-phase Converters and Virtual Microgrid Implementation Utilizing the Power Hardware in the Loop Concept”, IEEE Applied Power Electronics Conference and Exposition, 2010.	Conference
B. Ramachandran, S. K. Srivastava, Cartes, D. A. , Edrington, C. S. , and Subramanian, S., “Intelligent Agent-based Auction by Economic Generation Scheduling for Microgrid Operation”, IEEE Innovative Smart Grid Technologies, 2010.	Conference
B. Hacker, S. Azongha, and C. S. Edrington , “PHEV Impacts on Microgrid Systems”, IEEE Electric Power and Energy Conference, Montreal, Canada, Oct. 2009.	Conference
C. S. Edrington , O. Vodyakho, and B. Hacker, “Virtual Battery Charging Station Utilizing Power-Hardware-in-the-Loop: Application to V2G Impact Analysis”, IEEE Vehicle Power and Propulsion Conference, Lille, France, September 2010.	Conference

C. S. Edrington, S. Balathandayuthapani, and J. Cao, "Analysis and Control of a Multi-string Photovoltaic (PV) System Interfaced with a Utility Grid", IEEE Power and Energy Society General Meeting, Minneapolis, Minnesota, July 2010.	Conference
C. S. Edrington, S. Balathandayuthapani, and J. Cao, "Analysis of Integrated Storage and Grid Interfaced Photovoltaic System via Nine-switch Three-level Inverter", <i>accepted</i> to IEEE Industrial Electronics Conference, Glendale, AZ, 2010.	Conference
M. Saghaleini, B. Mirafzal, and C. Edrington, "Regenerative Energy Management for Pulse-Loads in Dual DC-AC Micro-grids", <i>accepted</i> to IEEE Industrial Electronics Conference, Glendale, Arizona, November.	Conference
S. F. Azongha, S. Balathandayuthapani, C. S. Edrington, J. P. Leonard, "Grid Integration Studies of a Switched Reluctance Generator for Future Hardware in the Loop Experiments", <i>accepted</i> to IEEE Industrial Electronics Conference, Glendale, AZ, 2010.	Conference
B. Ramachandran, S. Srivastava, D. Cartes, and C. Edrington, "Distributed Energy Resource Management in a Smart Grid by Risk Based Auction Strategy for Profit Maximization," <u>Proceedings of the IEEE Power and Energy Society General Meeting</u> , Minneapolis, Minnesota, 2010.	Conference
Siyu Leng, Yi-Yop Chung, Chris Edrington, David Cartes, "Real-Time Coordination of Multiple Reconfigurable Adjustable Speed Drives for Power Quality Improvement," <u>Proceedings of the IEEE Power and Energy Society General Meeting</u> , Minneapolis, Minnesota, 2010.	Conference
Thomas Tracy Jr., "Design, Modeling, Construction, and Flow Splitting Optimization of a Micro Combined Heating, Cooling, and Power System," M.S. Thesis. Department of Mechanical Engineering, Florida State University. (J.C. Ordonez , Advisor)	Thesis
H. Wen, J.C. Ordonez and J.V.C. Vargas, "Single Solid Oxide Fuel Cell Modeling and Optimization," under review, 2010.	Journal
M.V.A. Pereira, J.V.C. Vargas, S.C. Amico, J.A.R. Parise, R.S. Matos, J.C. Ordonez , "The Optimal Match of Streams for Maximum Heat Transfer from a Gas Fired Absorption Refrigeration Unit," ASHRAE Transactions, 2010.	Journal
J. C. L. Torrens, J.V.C. Vargas, E. C. Telles, A.B. Mariano, J.C. Ordonez , Biodiesel from Microalgae: The Effect of Fuel Properties on Pollutants Emissions. 20th International Congress of Mechanical Engineering, November 15-20, 2009, Gramado, RS, Brazil	Conference
E.M. Sommer, J.V.C. Vargas, L.S.Sanches, R.B.Valentim, J.C. Ordonez , Development and Experimental Validation of a Mathematical Model for Alkaline Membrane Fuel Cells (AMFC), 20th International Congress of Mechanical Engineering, November 15-20, 2009, Gramado, RS, Brazil	Conference
P.L. Moss, G. Au, E.J. Plichta, and J.P. Zheng, "Investigation of solid electrolyte interfacial layer development during continuous cycling using ac impedance spectra and micro-structural analysis", <i>J. Power Sources</i> , 189, 66 (2009).	Journal
J.P. Zheng, "High energy density electrochemical capacitors without consumption of electrolyte", <i>J. Electrochem. Soc.</i> 156, A500 (2009).	Journal
W. Zhu, J.P. Zheng, R. Liang, B. Wang, C. Zhang, G. Au, and E. J. Plichta, "Durability Study of Carbon Nanotube/Nanofiber Buckypaper Catalyst Support for PEMFCs", <i>J. Electrochem. Soc.</i> 156, B1099 (2009).	Journal
P.L. Moss, G. Au, E.J. Plichta, and J.P. Zheng "Study of Capacity Fade of Lithium-Ion Polymer Rechargeable Batteries with Continuous Cycling", <i>J. Electrochem. Soc.</i> 157, A1 (2010).	Journal
W. Zhu, D. Ku, J.P. Zheng, R. Liang, B. Wang, C. Zhang, S. Walsh, G. Au, and E. J. Plichta, "Buckypaper-Based Catalytic Electrodes for Improving Platinum Utilization and PEMFC's Performance", <i>Electrochimica Acta</i> , 55, 2555 (2010).	Journal
J. Chatterjee, T. Liu, B. Wang, and Jim P. Zheng , "Highly conductive PVA organogel electrolytes for applications of lithium batteries and electrochemical capacitors", <i>Solid State Ionics</i> , 181, 531 (2010).	Journal
G.Q. Zhang, R.Y. Liang, J.P. Zheng, M. Hendrickson, and E.J. Plichta, "Lithium-air Batteries Using SWNT/CNF Buckypapers as Air Electrodes" <i>J. Electrochem. Soc.</i> 157, A953 (2010).	Journal

P. Andrei, J.P. Zheng, M. Hendrickson, and E.J. Plichta, "Some possible approaches for improving the energy density of Li-air batteries" accepted by J. Electrochem. Soc.	Journal
Alex Huang, Mariesa Crow, Gerald Heydt, Jim Zheng, Steiner Dale, Yu Liu, "The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet", accepted by Proceedings of the IEEE.	Journal
W. Zhu, J.P. Zheng, R. Liang, B. Wang, C. Zhang, G. Au, and E. J. Plichta, "Ultra-Low Platinum Loading High-Performance PEMFCs using Buckypaper Supported Electrodes", accepted by Electrochemistry Communications.	Journal
J.P. Zheng, P. Andrei, M. Hendrickson, and E.J. Plichta, "The Energy Densities of Rechargeable Li-air and Li-air Flow Batteries" submitted to J. Electrochem. Soc.	Journal
G.Q. Zhang, J.P. Zheng, R. Liang, C. Zhang, B. Wang, M. Au, M. Hendrickson, and E.J. Plichta, " α -MnO ₂ /Buckypaper Composite Catalytic Air Electrodes for Rechargeable Lithium-air Batteries", submitted to J. Electrochem. Soc.	Journal
K. Huang, S. Srivastava, D. Cartes, L. Sun, Li-Hsiang, "Market-based multiagent system for reconfiguration of shipboard power systems," Electric Power Systems Research, v 79, n 4, p 550-556, April 2009	Journal
L. Liu, Z.C. Wu, H. Li , "A Single-stage Grid-connected Inverter with Wide Range Reactive Power Compensation using Energy Storage System (ESS)," in <i>Proc. 25th IEEE Applied Power Electronics Conference and Exposition, (APEC'10)</i> , Palm Springs, USA, Feb. 2010	Conference
Z.C. Wu, L. Liu, H. Li , "Extensive Real/Reactive Power Flow Control for a Single-stage Grid-connected Inverter Integrating with Micro Storage," in <i>Proc. 6th International Power Electronics Conference, -ECCE Asia- (IPEC-Sapporo 2010)</i> , Sapporo, Japan, June, 2010	Conference
Y. Zhou, L. Liu, H. Li , "Real Time Digital Simulation (RTDS) of a novel Battery-integrated PV System for High Penetration Application," in <i>Proc. 2nd International Symposium on Power Electronics for Distributed Generation Systems(IEEE PEDG 2010)</i> , Hefei, China, June, 2010	Conference

PROPOSALS

Table IV shows a list of the proposals that are either submitted or are in the pre-proposal stage, based on the information provided to the PI by the co-PIs on this project. The purpose of the table is to give an indication of the effort by the PI and co-PIs to leverage the resources that this grant has provided to obtain further research funds to sustain this type of work. The participants are not a complete listing, but reflect only the involvement of the PIs from this project.

Table IV

Proposal Working Title	Participants Associated with this Grant	Agency	Amount
URISE (Undergraduate Research In Sustainable Energy)	C. S. Edrington, D. Cartes	State of Florida	\$400K
Early Career: High-fidelity Large-scale Power System Analysis: Application to High-Penetration Distributed Energy Resources	C. S. Edrington	DOE	\$750K
Uncertainty Propagation and Quantification Using Probability and Evidence Theories Based Approaches for Large Scale Power Systems	C. S. Edrington	DOE	\$1.1M

A Nationwide Consortium of Universities to Revitalize Electric Power Engineering Education by State-of-the-Art Laboratories	C. S. Edrington	DOE	\$25K
Development of Advanced Surrogate Modeling for Analysis of High Penetration DER in Large Scale Power Systems	C. S. Edrington	NSF	\$630K
Energy Efficient Building Systems Regional Innovation Cluster Initiative - "Se-Best"	D. Cartes, H. Li, C. S. Edrington, J. Zheng, J. Ordonez	E-RIC/DOE	\$16.6M
Integrated Building Energy Consortium	D. Cartes, C. S. Edrington	E-RIC/DOE	\$1.8M
International Collaboration Group on Solar Cell Technologies Development	J.P. Zheng	Chinese Academy of Sciences	\$877 K
3-D Nanofilm Asymmetric Ultracapacitor, a Phase I SBIR Project	J. P. Zheng	Department of Energy	\$30 K
3-D Nanofilm Asymmetric Ultracapacitor, a Phase II SBIR Project	J. P. Zheng	Department of Energy	\$225 K
In-Pile Temperature Monitor and Control for ATR	J. P. Zheng	Idaho National Laboratory	\$150 K
Study Stability and Reliability of PEMFCs made with Buckypaper Supported Catalytic Electrodes	J. P. Zheng	Bing Energy Inc.	\$16 K
Develop Li/Air Rechargeable Batteries	J. P. Zheng	Savannah River National Laboratory	\$30 K
Research and Development on Some Critical Issues for High Energy and Power Densities, and Good Lifespan of Li-air Batteries	J.P. Zheng, P. Andrei, T. Liu	US Army CERDEC	\$100 K
Development of a Low-Cost and High-Efficiency 500 W Portable PEMFC System	J.P. Zheng, W. Zhu, R. Liang	Department of Energy	\$384 K
Electrolyte Development for Li-ion Capacitors	J. P. Zheng	US Advanced Battery Consortium (USABC)	\$419 K
In Situ Electrochemical-NMR Spectroscopy of Lithium Rechargeable Batteries	R. Fu, J.P. Zheng	NSF	\$198 K

Smart Grid Research, Development, and Demonstration, Area of Interest II	Cartes, D; et al.	Department of Energy	\$2,998,694
Smart Grid Research, Development, and Demonstration Area of Interest I	Cartes, D; et al.	Department of Energy	\$4,853,310
Science Master's Program	Cartes, Dave; Culaba, Alvin	NSF	\$698,785
TIGER Discretionary Grants (subcontract)	Cartes, D; et al.	DOT	\$1,490,000
Science in Energy and Environmental Design	Cartes, D; et al.	NSF	\$72,490
Commercialization Plan for Distributed Intelligent Agency Based Control Solutions (DIAC Solutions) FSU#3	Cartes, Dave	FESC	\$7,500
Recovery Act: Energy Efficiency and Conservation Block Grants: Retrofit Ramp-up and General Innovation Fund PART I	Cartes, Dave	DOE	\$3,499,998

AWARDS

Table VI lists honors, recognitions, and awards that have received based on work associated with this grant.

Table VI

Investigator	Award
Juan Ordonez	W. Hang, J.C. Ordonez and J.V.C. Vargas, "Single SOFC Modeling and Optimization," ESRDC Annual Meeting, University of South Carolina, June 2010. Honorable mention.

CONCLUSIONS

Due to budget cuts at the initial stage of the project, the original \$1M that was awarded was cut to approximately \$719K and additionally the 3rd year of the project was left unfunded. The original set of PIs included Dr. Farukh Alvi who at this initial stage decided to decline participation in the research effort since he could fund the same type of work under FCAAP. Due to this, the portion of the Statement of Work relating to Dr. Alvi's work will not be pursued and essentially does not impact the overall objectives of the project.

Due to the importance of solar PV installations that are being proposed and constructed in the State of Florida, a modification to the scope of work by Dr. Edrington was initiated in order to address control, stability, and integration of high levels of penetration of solar PV in existing and new grid topologies. A new student Jianwu Cao begins working on this research area starting in the fall semester 2009.

Another modification to the overall structure of the effort was that Dr. Steurer could essentially pursue the IEEE 1547 Standards work out of other monies that were at his disposal. Due to budget shortfalls we were able to recapture that money and use it for some equipment purchases, summer support and scientists.

There were certain financial issues that were faced during the time between the last report and this current one. First was the reduction of the grant by approximately \$40K around the December 2009/January 2010 time frame. Unfortunately this was not modeled correctly in the spreadsheet that was used for monthly budget overviews, thus the burn rate was actually too fast during this period. Additionally, during this time it was felt that due to some tuition issues that did not allow students to receive waivers and then was rectified, that we would actually also be receiving that money back into the grant; however the money was not returned in that manner leaving us short when we found that the \$40K had not been represented in the monthly budget meetings. At this point of discovery, which was around the May 2010 time frame, Dr. Edrington removed all of his students and post-doctoral researchers from the project and placed them on a synergistic navy project in an effort to support the remaining students. The grant is now back on track with regards to spending and is due to exhaust the remainder of the funding by December 2010.

In general the research team has made excellent progress toward the research goals that were set forth in the original SOW, as evidenced by the level of publications in national and international forums. Additionally, the educational goals are being amply met and the funding is providing opportunities for undergraduate and graduate students to achieve an education in an area that is clearly of national importance. Moreover, the PIs have utilized the knowledge and opportunity provided for by the grant to write additional proposals that if funded will help support sustainable energy initiatives.