Final Scientific / Technical Report

SMART GRID INTEGRATION LABORATORY

DOE Prime Contract Award: DE-SC-0005294
DOE Project Officer: Arthur Katz
Recipient: Colorado State University
Principal Investigator: Wade Troxell

11/28/12

This report is the Final Scientific/Technical Report for the Congressionally Directed Program to the Department Of Energy for the Colorado State University faculty support of its SMART GRID INTEGRATION LABORATORY under DE-SC-0005294 which will be used for teaching, experimentation, and testing of Smart Grid Technology.

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Executive Summary:

The Colorado State University Smart Grid Integration Laboratory is a Congressionally Directed Project (CDP) with the original program requested in three one-year increments for staff acquisition, curriculum development, and instrumentation – all which will benefit the Laboratory. This report focuses on the second phase of staff acquisition and education administered by DOE Project Officer Arthur Katz. Using this CDP funding, we have developed the leadership and intellectual capacity for the SGIC. This was accomplished by investing (hiring) a core team of Smart Grid Systems engineering faculty focused on education, research, and innovation of a secure and smart grid infrastructure. The Smart Grid Integration Laboratory is housed with the separately funded Integrid Laboratory as part of CSU's overall Smart Grid Integration Center (SGIC). The period of performance of this grant was 9/15/2010 to 9/14/2012 which included one no cost extension due to time delays in faculty hiring.

This 2nd CDP year funding request ($874,000.74) follows on the FY09 funding, DE-OE0000070 administered through DOE, will develop leadership and intellectual capacity within the CSU SGIC Smart Grid Integration Laboratory by hiring and funding a core team of Smart Grid Systems Engineering faculty focused on education, research, and innovation of a secure and smart grid structure.

The mission of the DOE, Office of Electricity Delivery and Energy Reliability is to lead national efforts to modernize the electric grid; enhance security and reliability of the energy infrastructure; and facilitate recovery from disruptions to energy supply. CSU's Smart Grid Innovation Center with its' Smart Grid Integration Laboratory apply directly to this DOE mission as a nucleus of research, knowledge and facilities in which to determine requirements and technologies necessary for a robust, secure grid, evaluate and validate smart grid solutions, and educate technicians and professionals. The content of this project is integral into moving the DOE's mission forward.

Anticipated objective of this program is to build a foundation to 1) Develop faculty leaders to lead education and research to create secure smart grid infrastructures, 2) Develop and teach graduate systems engineering courses on Smart Grid, 3) Conduct innovative research and develop an externally sponsored research program in conjunction with the InteGrid Laboratory, and 4) initiate and lead collaborations achieving smart grid innovations. The Smart Grid Integration laboratory public purpose is to build a foundation to 1) develop/teach academic and professional smart grid systems engineering courses, 2) conduct innovative research through partnerships, and 3) serve community with university outreach and economic development. This achieves the higher purpose of contributing to energy independence, secure energy supplies, and energy efficiencies in all environmental and economic conditions.

The Smart Grid Integration Laboratory's focus is to build foundations to help graduate and undergraduates acquire systems engineering knowledge; conduct innovative research; and team externally with grid smart organizations. This project has developed faculty leaders with the intellectual capacity to inspire its students to become leaders that substantially contribute to the development and maintenance of Smart Grid infrastructure through topics such as:

(1) Distributed energy systems modeling and control
(2) Energy and power conversion
(3) Simulation of electrical power distribution system that integrates significant quantities of renewable and distributed energy resources
(4) System dynamic modeling that considers end-user behavior, economics, security and regulatory frameworks

(5) Best practices for energy management IT control solutions for effective distributed energy integration (including security with the underlying physical power systems)
(6) Experimental verification of effects of various arrangements of renewable generation, distributed generation and user load types along with conventional generation and transmission

Understanding the core technologies for enabling them to be used in an integrated fashion within a distribution network remains is a benefit to the future energy paradigm and future and present energy engineers.

Key Accomplishments under this program:

a. Support of Faculty and SGIL development
b. Funding and hiring of 3 Faculty
c. Creation and delivery of 1 new course: (Microgrid as a Foundation for Smart Grid Education; partial funding of Smart Grid Boot Camp)
d. Delivery of 4 new courses
e. Conference participants and presenters at over 29 Conferences
f. Development of the Smart Grid Boot Camp Course
g. Smart Grid Curriculum Offering
h. 27 publications

Actual Accomplishment with Goals and Objectives of the Project

DOE through congressionally directed funding contracted with Colorado State University under DE-OE-0000070 to begin Phase 1 of developing the Smart Grid Integration Laboratory (SGIL). The six (6) goals of this contract were:

- Hire last professor of the 3 professors
- Curriculum Framework
- Course and Training Development
- Education and Training
- Quality Monitoring
- Research

We have met these goals as referenced in Table 1. Four graduate engineering courses have been offered as part of a Smart Grid Curriculum as shown in Table 5. Eight publications were written by the professors as shown in Table 6.

Table 1 Objectives and Outcomes Summary of SGIL Phase II

Objective / Goal	Outcome
1. **Goal:** Hire remaining faculty hire	Status: **Met.** Hired Dr. Allen Robinson of Carnegie Mellon for remaining mechanical engineering faculty hire
2. **Goal:** Conduct a national search to identify top faculty candidates in smart grid integration and making a global impact	Status: **Met**.

Table 1 Objectives and Outcomes Summary of SGIL Phase II	
Objective / Goal	**Outcome**
3. **Goal:**	Status: **Met.**
4. Survey the field of smart grid industry needs and develop a plan for educating a smart grid workforce. **Goal:** Develop a smart grid systems integration education roadmap	Status: **Met.**
5. Develop a framework and a set of courses to educate a smart grid workforce.	Status: **Met.**
6. Develop the content for one course.	Status: **Met.**

Task 1 Formation of Smart Grid Integration Laboratory

The Smart Grid Integration Laboratory (SGIL) is part of the SGIC, a multi-faceted project led by Colorado State University (CSU) in conjunction with the separately supported Integrid Lab used for training with collaboration from industry to support smart grid education and training. The SGIC objectives are elucidated below:

- Objective: Provide educational training to recognized standards to the next generation smart grid systems engineers and scientists, and perform leading smart grid-related research leading to innovation of new technologies and services enabling high penetration of renewable energy
- Objective: Further the current understanding of renewable microgrid design, hybrid systems, and premium power systems use "cell architecture" for demonstrating core smart grid capabilities in overall distribution system operation
- Objective: Invest in megawatt scale generation for *in situ* grid interconnection to operation conventional and renewable generation sources coupled with dynamic load banks in order to provide realistic physical simulation
- Objective: Develop advanced grid control and stabilization technologies that can be setup alongside conventional software power systems simulation tools for the development and testing of advanced grid control concepts
- Objective: Develop partnerships with conventional, distributed, and renewable power generating utilities and technology providers in order to further the adoption and testing of these system solutions
- Objective: Expand on functional capabilities in order to further capacity management at substations, voltage/VAR management, and intentional islanding, all using Distributed Energy Resources. Develop appropriate analytical tools to evaluate, install, monitor, analyze, and optimize the use of those technologies within a system. Such tools must work with current equipment, software, and operating procedures of an electric utility

The SGIL, as show in Figure 1, is a crucial and integral part of the SGIC, which is capable of educating students in operating the electric power grid system with the integration of renewable power generation sources along with providing the ability of active participation with the end users. Renewable systems, such as solar-battery, wind-battery or wind-diesel-battery systems, have been demonstrated successfully in recent years, but the previous core technologies for enabling them to be used in a distribution utility network remained limited and not well understood.

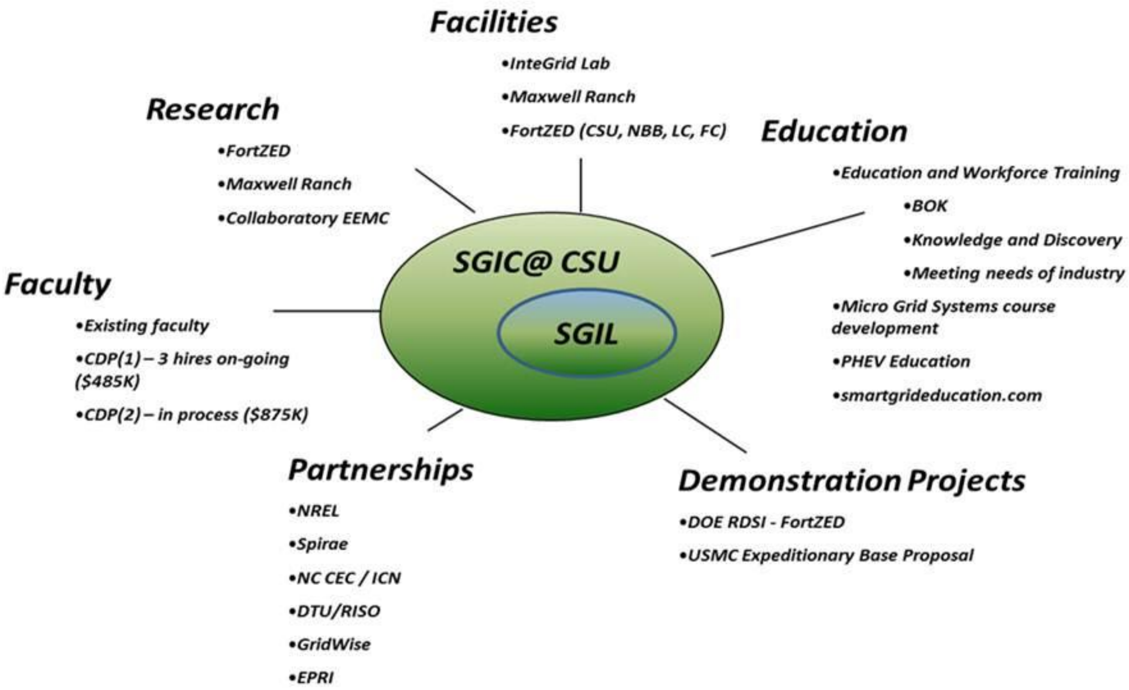

Figure 1 CSU Smart Grid Integration Center and Laboratory

Task 2 Faculty Hiring

Two very well-known electrical engineering professors were hired, Dr. S. Suryanarayanan and Dr. L. Yang within the 1st phase and supported within the second phase. Dr. Allen Robinson was hired during this period as the third faculty hire. Difficulty in finding an appropriate mechanical engineering recruit proven difficult and resulted in hiring schedule delays.

The management of the SGIL consists of the program team using a program management plan, a hiring plan, an educational committee, and an education development plan. The results of these plans are the results as indicated in the results as elaborated in this report. The program team is shown in Table 2.

Table 2 SGIL Project Team

Name	Organization	Program Role
Wade Troxell	COE Department of the Dean	PI, Program Director, Education Committee
Ann Batchelor	CSU Ventures	Program Manager, Education Committee
Anita Montgomery	CSU OSP	CSU Grants

Table 2 SGIL Project Team		
Name	**Organization**	**Program Role**
Dan Zimmerle	COE InteGrid Laboratory	Education Committee
Luiqing Yang	New Faculty Hire, CSU EECE	Education Committee
Sid Suryanarayanan	New Faculty Hire, CSU EECE	Education Committee
Allen Robinson	New Faculty Hire, CSU ME	Education Committee

An SGIL Advisory Board was formed by the Primary Investigator, Wade Troxell, and consists of those members as depicted in Table 3.

Table 3 SGIL Advisory Board Members		
Judy Dorsey	COE Advisory Board, Northern Colorado Clean Energy Cluster (NCCEC)	Advisor
Luis Garcia	COE Civil & Environmental Engineering Depart. Head	Advisor
Susan James	COE Mechanical Engineering past Faculty Head	Advisor
Ben Kropowski	National Renewable Energy Laboratory (NREL)	Joint Faculty POC
Tony Maciejewski	COE Electrical and Computer Engineering Depart. Head	Advisor
Jan Nerger	College of Natural Sciences, Dean	Advisor
Ron Sega	VP for Energy and the Environment, CSURF, CSU	Advisor
Bryan Willson	CSU Director of the Engines and Energy Conversion Laboratory; Director of Clean Energy Supercluster, Professor of ME	Advisor
Julie Zinn-Patti	Spirae, Inc.	Advisor, Training

Survey and Roadmap

Requirements for education were based on the findings from the separately funded Smart Grid Workforce Education Workshop (May 2009) sponsored by the City of Fort Collins, Northern Colorado Clean Energy

Cluster, Colorado State University Continuing Education, Spirae, and Siemens. Participants included decision makers from utilities, private industry, state and federal government, and academic institutions gathered to identify workforce needs and skills gaps. One of the crucial findings of this workshop was identified as the existence of barriers both in workforce education and in smart grid deployment. The knowledge gap of key stakeholders was identified as a major barrier. Immediate (next 2 years) areas of technology education identified were as:

- Power system simulation
- Voltage monitoring and control
- Residential and fleet electrical transportation
- Enterprise integration
- Cyber security
- Modeling and simulation
- Smart Grid applications
- Renewable energy and distributed generation markets
- Knowledge and skills for equipment installers
- Knowledge and skills for regulatory and policy makers

Future education and knowledge needed were identified as

- Smart grid controls
- Integrated energy management systems
- Systems integration
- Demand response technology

Course topics identified as the highest priority were grouped into the following categories:

- Introduction to Smart Grids – Smart Grid Basics
- Smart Grid Business – Strategy and Economics
- Smart Grid Technologies – System Design and Development; Renewable Power Generation; Distributed Power Generation

Target audiences for courses were identified as:

- Stakeholders
- Executive management
- Regulatory agencies
- Utilities
- Private research and development participants
- Technical operations staff including electrical engineers, mechanical engineers, software engineers for utilities and the private sector

Task 3 Curricula Framework and Course

(1) Distributed energy systems modeling and control
(2) Energy and power conversion

(3) Simulation of electrical power distribution system that integrates significant quantities of renewable and distributed energy resources
(4) System dynamic modeling that considers end-user behavior, economics, security and regulatory frameworks
(5) Best practices for energy management IT control solutions for effective distributed energy integration (including security with the underlying physical power systems)
(6) Experimental verification of effects of various arrangements of renewable generation, distributed generation and user load types along with conventional generation and transmission

Before building a specific course commences, the needs assessment and course outline for it shall be reviewed by and approved by the educational committee. Competencies required are academic degree program development, delivery and administration, professional training development, delivery and administration, smart grid subject matter expertise, smart grid / renewable energy labs, and education and training program management. Needed professional courses identified by industry to date are listed below:

- Smart Grid Boot Camp
- Course 1 Introduction to Smart Grid
- Network Planning to Support Smart Grid
- Smart Grid and Power Systems Operations
- System Protection and Relaying
- Smart Grid Controls

This survey was used to guide the formation of the SGIL Education Plan, SGIL Education Committee, the SGIL Project Management plan, and strategic planning for future courses. The Education plan for the entire SGIL program, using the Smart Grid Educational Workshop report as guide, is as follows:

- Deliver two smart grid education tracks: an Academic track and a Professional track
- Deliver 5 courses and 1-2 lab courses in the Academic track
- Deliver 5-7 educational lab courses in the Professional track, 1 Boot Camp course
- Develop an Introduction to Smart Grid course
- Deliver smart grid training using a variety of media (asynchronous and synchronous mechanisms)
- Promote knowledge discovery through a comprehensive smart grid program providing breadth and depth of topics
- Meet industry employment needs by supplying trained smart grid engineers and management professionals
- Meet the needs of the existing energy workforce by providing opportunities for career growth and providing the knowledge of smart grids current employees need to make sound business and engineering decisions
- Create stackable programs that provide for ongoing career growth from the technician level through master's level engineers.

Most courses offered in both tracks will be available to students via distance-learning allowing for global scalability. The experiential lab components, which are offered at the CSU/Spirae InteGrid Lab, are essential for sufficient transfer of knowledge and skill to workplace performance. The target audience includes professionals from utilities, Regional Transmission Operators (RTOs), transmission owners, energy service providers, technical solution and component vendors; IT services providers, and government agencies.

Curricula Developed

Smart Grid Bootcamp

Two course outlines were developed per the needs identified by industry for the initial course work for the Smart Grid Bootcamp: 1) Fundamentals of Micro-Grids, and 2) Renewable Energy in Island Power Systems. Using organizational curriculum development requirements, the first course was developed. Our objective was to first develop the course which was of imminent industrial need as the first course and then the second course. The Smart Grid Bootcamp, developed by Spirae under this program, was delivered in Phase 2.

Power System Fundamentals coursework was delivered, reviewed, and presented 18-22 June 2012 at the CSU Integrid and at Spirae in Fort Collins. The organizations represented in the class were UC Denver, WAPA, United Power, Inc., and Spirae to 15 students from a variety of backgrounds. Front Range Community College participated in the course marketing and delivery. Smart Grid Bootcamp II: Operations and Control and III: Distributed and Renewables Integration are scheduled Scholarships from the Colorado State Energy Sector Partnership is providing $3000 for each participant in each course. Participant job titles included Energy Management Specialist, Software Engineer, Analyst, Applications Specialist, Electrical Engineer – Transmission Planning, Full Time Student, and Data Specialist. The student evaluation summary is provided as Appendix A in this report.

The course outlines for each course are included below in this report.

Course Outline: Fundamentals of Microgrids

Microgrid Introduction

1. Definition of Microgrid
    a. Grid-tied versus islanded electrical systems
    b. Concepts of a "stiff" system or "infinite bus," and why islanded systems behave differently from grid-connected systems.
    c. Definition of microgrid as a small islanded electrical system
2. Components of microgrid power system
    a. Generation
    b. Loads
    c. Distribution
3. Electrical power and power control concepts
    a. Voltage/Frequency
    b. Real/reactive power
    c. Understanding "per-unit" measurements
    d. Anti-islanding standards
4. Load and distribution characteristics
    a. Real and reactive loads
    b. Inductive loads with particular emphasis on motor starting loads
    c. Distribution impedance, voltage drops

    d. Issues caused by unstable voltage and frequency
5. Intermittent and transient behavior
    a. Division into planning, reserve and regulation timescales
    b. Fundamentals of planning systems
    c. General approaches to reserve and regulation
6. How microgrids differ from grid-tied systems
    a. System inertia and transient times decrease as system size decreases
    b. How transient timescales drive control strategies and equipment

Multi-point Generator Control: Conventional Generation

1. Types of generation systems
    a. Variable speed versus fixed speed machines
    b. Synchronous machines & induction machines
    c. Power electronics and inverters
    d. Inertia, ride-through, and surge load support
2. Single-machine control concepts
    a. Speed = frequency
    b. Excitation = voltage
    c. Governors, gain and response characteristics
    d. Voltage regulators, gain and response characteristics
    e. Performance in load-step conditions
3. Value of "ganged" or "bussed" generators
    a. Specific fuel consumption by generator load and size
    b. Performance in load-step conditions, neglecting control issues
4. Multi-machine control concepts
    a. Fundamentals of 1^{st}-order control system for ganged generators
    b. Issues with multi-machine gains, response tuning and control fights
    c. Typical COTS solution framework and application to island systems
    d. Isochronous master & load sharing concepts
    e. Baseload (droop) and master generator sharing concepts
5. Practical implementation issues
    a. Control variations due to distance between generators
    b. Distribution system impedance – to be covered later
    c. Sensing issues – latency and accuracy
    d. Harmonics

Load-side and Distribution Concepts

1. Impact of distribution on microgrids
    a. Reactive power support and circulating currents
    b. Line losses and voltage drop
    c. Absorption of transients, recovery times
2. Distribution systems and tradeoffs
    a. Single- and multi-phase systems, phase balance topics
    b. Radial and ring systems

c. 1st-order concepts behind protection systems
d. Choice of voltage levels
e. DC systems
3. Demand response
a. Definition of demand response
b. Concept of response granularity
c. Deterministic versus stochastic control models
d. Estimating latency and transient response characteristics
4. Storage concepts
a. Variation in storage concepts by times scales – energy buffering, power buffering and transient response
b. Types of storage: Battery, capacitor, super-capacitor, inertial
c. Using thermal storage to reduce demand or absorb excess generation: Ice or heat
d. Interconnect methods and issues

Moving Toward Integrated Systems

1. Introduction to integrated systems approach
    a. The system-of-systems methodology
    b. Modeling systems at varying timescales
    c. Methods and tools for systems approach
    d. "Objective function" and optimization approach
    e. Decision support systems
2. Advanced control system concepts, active research and development topics
    a. Exploiting high-speed communications for distributed controls
    b. Robust control applications
    c. Integrated and economic dispatch concepts
3. Examples or discussion
    a. Handling transients through demand response
    b. Optimizing system deployment to maximize fuel efficiency, increase security

The overall course outline for the Renewable Electricity Systems for Microgrids and Island Power Systems course is shown below.

Course Outline: Renewable Electricity Systems for Microgrids and Island Power Systems

Introduction

1. What's in this course:
    a. Focus on microgrids, specifically small island power systems … rather than utility-scale systems, grid operations, or related topics
    b. Emphasis on widely applicable systems → wind, PV, biomass … rather than niche site applications: Hydroelectric, active geothermal, etc.
    c. Electricity generation (and some distribution) with little on thermal or efficiency
    d. Generally technical rather than economics
2. Depth of coverage
    a. "Fundamentals" coverage of key renewable resources

b. Discuss the "complete problem" from energy collection to power output, but "There's another course under every topic"

General Characteristics of Renewable Energy Sources for Electricity

1. Renewable sources
   a. Definitions "renewable" … "distributed" … "local"
   b. Quick touch on conventional generation for microgrids
   c. Broad versus location-specific sources: hydro, wind, solar, geothermal and biomass …
   d. Why current island systems focus on combination of conventional, PV & wind
   e. Benefits of combined heat and power
2. Microgrid basics
   a. Definition
   b. System elements: generation, loads and distribution
   c. Categories of scale, AC and DC systems
   d. Static versus dynamic configurations
3. Interconnect fundamentals
   a. Basic requirements for safe and effective interconnect
   b. Interconnection at the architectural level
   c. Voltage, frequency and harmonics
   d. IEEE 1547 interconnection standards
   e. IEEE 519 harmonic distortion standard
4. Intermittent and transient behavior of renewables
   a. Transient concepts – timescale, magnitude and frequency
   b. Impact of aggregating multiple units on transient magnitude and frequency
   c. Division into planning, reserve and regulation timescales
   d. Fundamentals of power planning systems
   e. General approaches to reserve and regulation
   f. Impacts at low- and high-penetration levels

Fundamentals of Wind Power

1. A quick inventory of turbine types
   a. Lift, drag and flutter machines
   b. Horizontal and vertical axis architectures
   c. The 2X2 matrix of common turbine types
2. Physics of wind power
   a. The power available in wind … introducing $P = \frac{1}{2}\rho A V^3$
   b. Betz' law: The theoretical limit on turbine performance
   c. Claims and controversies regarding Betz' law … the hype around cowlings, wind shaping, stators and similar enhancements
   d. Turbulence and its impact on performance
3. Practical assessment of wind power potential
   a. Assessing wind speeds
   b. The Weibull/Rayleigh wind speed distribution and its impact on actual power production

   c. Difference between the human experience of "windy" and assessing potential power production.
   d. Cut-in, cut-out and rated speeds
   e. Claims and controversies regarding low cut-in speed
4. Drive trains and interconnect methods
   a. Classic induction drivetrains, DFIG and synchronous machines
   b. Power electronics methods
   c. Current COTS solutions for small distributed wind systems
5. Common turbine issues and current COTS solutions
   a. Gearbox losses and reliability – low-speed generators – starting torque issues
   b. Torque oscillations (particularly in VAWTs), impacts and solutions
   c. Temperature effects, ice
   d. Storms: Control at high wind speeds, protection via lock or tilt-down
   e. Dust & cooling
   f. Avian impacts
6. Transients and microgrid impacts
   a. Physics behind high wind-power transients – the V^3 effect
   b. Comparison of wind transients to conventional generation response transients
   c. Concepts behind power buffering and smoothing
7. Assessing wind's potential to displace significant quantities of conventional fuel
   a. Planning concepts
   b. Sizing of turbines for targeted displacement levels
   c. Dealing with insufficient or excess generation

Fundamentals of Photovoltaic Systems

1. 1st-order physics of photovoltaic systems
   a. Frequency spectrum of sunlight
   b. Physics of direct light-electricity conversion w.r.t. frequency spectrum
   c. Types of solar radiation: Direct normal, diffuse, global
   d. Theoretical limits on PV efficiency
   e. Solar cell types & new technology directions
2. PV modules and behaviors
   a. From cells to modules
   b. "Strings," parallel cells and protection diodes
   c. Impact of partial shading on string performance
   d. Impact of temperature on efficiency
      i. $T_{cell} \cong T_{air}(T_{norm} - 20)(\frac{S}{800})$ (Ross & Smokler, 1986)
      Where S is insolation level and T_{norm} is cell temperature under nominal operating conditions ($S = 800\frac{W}{m^2}, T_{air} = 20\,C, V_{wind} = 1\frac{m}{s}$
   e. Impact of orientation & tilt
   f. Concentration – methods and value
3. Practical assessment of PV power potential
   a. Estimation or measurement of insolation
   b. Corrections to actual performance
4. Electrical interconnect and associated controls

    a. Anatomy of a typical PV inverter system
    b. Module voltage levels, and impact on inverter efficiency
    c. V/I curves
    d. Maximum peak-power tracking
    e. Cut-in/cut-out thresholds
5. Transients and microgrid impacts
    a. Variation in transients with system size
    b. Reactive power generation (i.e. voltage support) issues
    c. Comparison of PV transients to conventional generation response transients
    d. Concepts behind power buffering and smoothing
6. Potential of PV to displace significant quantities of conventional fuel
    a. Planning concepts
    b. Sizing
    c. Control concepts to deal with excess generation

Introduction to Biomass and Fuel Substitution

1. Conventional biomass applications
    a. External combustion or heat engines (Rankine, Stirling, etc.)
    b. Pointer to further references
2. Fuel substitution for small systems
    a. Methane or syngas substitution in diesel engines
    b. Engine modifications and control topics
    c. Engine issues: Sulfides and other contaminants
    d. Impact of entrained CO_2 on performance
3. Methane production
    a. Produced methane basics
    b. Feedstock identification
    c. Anaerobic digestion
    d. Operational challenges with anaerobic digestion
    e. Catalytic systems
    f. Operational challenges for catalytic systems, sulfur contamination
    g. Gas storage options and issues
4. Syngas production
    a. Syngas basics
    b. Feedstock identification
    c. COTS pyrolysis methods
    d. Gas storage options and issues
    e. Secondary processing to produce liquid fuels

Integration and Optimization using a System-of-Systems Approach

1. Introduction to integrated systems approach
    a. The system-of-systems methodology
    b. System modeling at varying timescales
    c. Methods and tools for systems approach

    d. Defining an appropriate "Objective function" and optimization approach
    e. Decision support systems
2. Advanced control concepts, active research and development topics
    a. Control of high-frequency transient components
    b. Integrating power- and energy-buffering with renewables
    c. Optimizing microgrid performance by operating renewables with reserve capacity or "off optimum operating points."
    d. Exploiting high-speed communications for distributed controls
    e. Integrated and economic dispatch concepts

Renewable To-Do Items

1. Get an overview of PV-WATTS and HOMER for overview
2. Get turbulence description for small wind
3. Layman's descriptions of 1547 and IEEE 519

The Renewable Electricity Systems for Microgrids and Island Power Systems CSU SGIL course was further developed for professionals. Course topics were divided into segments and presented as follows

- Introduction to Renewable Energy in Island Power Systems
- Resource assessment – Resource Estimation
- Collectors
- Electrical Interconnect
- Microgrid Integration
- Adverse Conditions

As new courses are developed, they will follow the training standards and processes as required by their respective departments, CSU curriculum requirements and its curriculum acceptance process, and those required by the SGIL Education Committee. Course development was the focus this Phase 2 funded separately from the Phase 1 grant. Course Delivery Methods are identified in Table 4.

Table 4 Course Delivery Methods Identified		
Methods of Information Delivery	**Professional Track Short Courses**	**Academic Track Courses**
Experiential Labs	Y	Y
Distance Learning	Y	Y
On-Site Education	Y	Y
Industry locations	Y	Y

New CSU Smart Grid Curricula Offered

The five courses in Table 5 were developed previously by the new SGIL professors and are being used to quickly fulfill the requirements for subject education as requested by the smart grid community survey.

Table 5 Smart Grid Courses Offered		
Professor	**Smart Grid Courses**	**Offered**
Yang	Spread Spectrum Communications	Fall 2010

Table 5 Smart Grid Courses Offered		
Professor	**Smart Grid Courses**	**Offered**
Suryanarayanan	Electric Power Engineering: Introduction to power system market Operations	Fall 2010
Suryanarayanan	Electric Power Quality	Spring 2011
Yang	Signal Processing for Power System Analysis	Fall 2011
Yang	Signal Processing for Power Systems II	Spring 2012

Products Developed Under This Grant

Research and education, and making a global impact in smart grid innovations and technologies are part the original intent for the SGIL. The following publications partially funded in terms of salaries from this DOE grant are summarized in Table 6 and show expertise and research in the areas pertinent to the SGIL and its objectives.

Table 6 Publications from Smart Grid integration Lab Faculty*	
1.	M. G. Simões, R. Roche, E. Kyriakides, A. Miraoui, B. Blunier, K. McBee, S. Suryanarayanan, P. Nguyen, and P. Ribeiro, "Smart-grid technologies and progress in Europe and the USA," in 2011 IEEE Energy Conversion Congress and Exposition (ECCE), Phoenix, AZ, USA, pp. 1-8, Sep. 2011
2.	J. Giráldez, A. Jayantilal, J. Walz, H. E. Brown, S. Suryanarayanan, S. Sankaranarayanan, E. Chang, "An evolutionary algorithm and acceleration approach for topological design of distributed resource island," in Proc. 2011 Proc. IEEE PES PowerTech, Trondheim, Norway, Jun 2011
3.	P. Zhao, S. Suryanarayanan, M. G. Simões, "A conceptual scheme for cyber-physical systems bas energy management in building structures," in Proc. 9th IEEE/IAS International Conference on In Applications (IndusCon), São Paulo, Brazil, Nov. 2010.
4.	X. Cheng, R. Cao and L. Yang, "On The System Capacity of Relay-Aided Power Line Communications," in Proceedings of IEEE International Symposium on Power Line Communications and Its Applications, Udine, Italy, April 3-6, 2011
5.	W. Zhang and L. Yang, "SC-FDMA for Uplink Smart Meter Transmission over Low Voltage Power Lines," in Proceedings of IEEE International Symposium on Power Line Communications and Its Applications, Udine, Italy, April 3-6, 2011
6.	X. Chen, F. Qu and L. Yang, "OFDM-IDMA for Power Line Communications," in Proceedings of IEEE International Symposium on Power Line Communications and Its Applications, Udine, Italy, April 3-6, 2011
7.	R. Carnieletto, D. I. Brandão, S. Suryanarayanan, M. G. Simões, F. A. Farret, "Smart Grid Initia multifunctional single-phase voltage source inverter," IEEE Industry Applications Magazine, v no. 5, pp. 27-35, Jun 2011

Table 6 Publications from Smart Grid integration Lab Faculty*	
8.	H. E. Brown, S. Suryanarayanan, S. A. Natarajan, "Improving reliability of islanded distribution systems with distributed energy resources via optimal addition of feeder interties," IEEE Transactions on Smart Grid, June 2012
9.	P. Zhao, S. Suryanarayanan, M. G. Simões, An energy management system for building structures using a multi-agent decision-making control methodology,", IEEE Transactions on Industry Applications, May 2012
10.	L. Fang, D. Duan, L. Yang, and L. L. Scharf, "A Low-Complexity Frequency Estimator Exploiting Sinc Shape for Single-Tone Sinusoidal Signals Using Fourier Coefficients," IEEE Transactions on Signal Processing, 2012 (submitted)
11.	D. Duan, L. Yang and L. L. Scharf, ``Phasor State Estimation from PMU Measurements with Bad Data," in {\it Proceedings of IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing}, San Juan, Puerto Rico, December 13-16, 2011 (invited)
12.	J. Giráldez, S. Suryanarayanan, D. Zimmerle, "Impact of plug-in hybrid electric vehicles with vehicle-to-grid capabilities for peak-shaving and reliability in islanded distribution systems,", IEEE Transactions on Smart Grid, Oct 2011
13.	S. Suryanarayanan, H. E. Brown, "Implications of the Smart Grid Initiative on distribution systems engineering – Part 1: Characteristics of a smart distribution system and design of islanded distributed resources," Technical report to Power Systems Engineering Research Center (PSERC), Aug 2011
14.	S. Suryanarayanan, J. Giráldez, "Implications of the Smart Grid Initiative on distribution systems engineering – Part 2: Impact of plug-in hybrid vehicles (PHEVs) on distributed island resources," Technical report to Power Systems Engineering Research Center (PSERC), Aug 2011
15.	S. Suryanarayanan, S. Sankaranarayanan, E. Chang, J. Giráldez, A. Jaintilal, J. Walz, S. Natarajan, S. Rajopadhye, "Verifiable decision-making algorithms for reconfiguration of electric microgrids," Technical report to Xcel Research Foundation, Aug 2011.
16.	S. Suryanarayanan, E. Kyriakides, "Microgrids: A new solution to combat reduced power reliability," (in Greek), op-ed article in *Paideia-News*, *Xaravgi*, and *Politis* Newspapers in Cyprus, (Aug 2011)
17.	S. Suryanarayanan, S. Ranade, J. Mitra, et al., "Collaborative research: Customer-driven distribution microgrids – a holistic approach based on real-time dynamic simulations," Final report to Nat'l Science Foundation (NSF), Jul 2011
18.	S. A. Natarajan, V. Putkaradze, S. Rajopadhye, S. Suryanarayanan, "On the computational complexity of the distribution feeder reconfiguration problem," under preparation, IEEE Power Engineering Letters, Apr 2012
19.	P. Deng and L. Yang, ``A Secure and Privacy-Preserving Communication Scheme for Advanced Metering Infrastructure," in Proceedings of IEEE PES Conference on Innovative Smart Grid Technologies (ISGT), Washington Marriott Wardman Park, D.C., January 16-20, 2012.
20.	D. Duan, and L. Yang, "Phasor State Estimation from PMU Measurements with Bad Data," Smart Grid Live, September 25-27, 2012 Fort Collins, CO

Table 6 Publications from Smart Grid integration Lab Faculty*	
21.	L. Fang, R. Griffin, D. Duan, and L. Yang, "A New Frequency Measurement Algorithm Tested with a Phasor Measurement Unit (PMU)," Smart Grid Live, September 25-27, 2012 Fort Collins, CO
22.	D. Palchak, S. Suryanarayanan, D. Zimmerle, "An artificial neural network in short-term electrical load forecasting of a university campus – A case study," accepted, ASME 2012 Energy Sustainability Conference, Jul 2012.
23.	D. Zimmerle, S. A. Natarajan, S. Suryanarayanan, P. M. Young, "Analysis of microgrid generation and control systems for Miramar Marine Corps Air Station," Technical report to Nat'l Renewable Energy Laboratory (NREL), Feb 2012.
24.	S. Suryanarayanan, E. Kyriakides, "Microgrids: An emerging technology to enhance power system reliability," invited article, IEEE Smart Grid Newsletter, [Online] {Available}http://smartgrid.ieee.org/march-2012/527-microgrids-an-emerging-technology-to-enhance-power-system-reliability (Mar 2012)
25.	M. Mohanpurkar, S. Suryanarayanan, "Accommodating unscheduled flows in electric grids using the analytic ridge regression," under review, *IEEE Power Engineering Letters*, Jun 2012
26.	**S.** Suryanarayanan, P. F. Ribeiro, M. G. Simões, R. Carnieletto, D. I. Brandão, "Smart interfaces and controls for emerging distribution systems," under review, in *Power Electronics for Renewable and Distributed Energy Systems: A Sourcebook of Topologies, Control and Integration*, Eds. S. Chakraborty, M. G. Simões, W. E. Kramer, Springer, May 2012

*These publications along with the corresponding DOE 241.3s have been electronically submitted.

Conference participation in the smart grid systems integration is necessary to further research and collaboration and increase the global presence of the SGIL. The conferences and conference information are summarized in Table 7.

Table 7 Conference Participation

Name of Conference	Location of Conference	Date of Conference	Conference Sponsor
Panel Session III – Distributed Generation, CAPS 10th Anniversary Celebration and NGIPS workshop	Tallahassee, FL	Oct 2010	CAPS
IEEE PES General Meeting	Minneapolis, MN	Jul 2010	IEEE
IEEE PES Transmission & Distribution Conference and Exposition	New Orleans, LA	Mar 2010	IEEE
US DOE Smart Grid Peer Review	Denver, CO	Nov 2010	DOE
6th Invitational International Symposium on Microgrids	Vancouver, BC, CA	Jul 2010	IEEE
IEEE Smart Grid Communications Conference	Brussels, Belgium	Oct 2010	IEEE Global Communications
IEEE Smart Global Communications Conference	Miami, FL	Dec 2010	IEEE

Table 7 Conference Participation			
Name of Conference	**Location of Conference**	**Date of Conference**	**Conference Sponsor**
9th IEEE/IAS International Conference on Industry Applications	San Paulo, Brazil	Nov 2010	IEEE/IAS
2010 US-Korea Conference on Science, Technology and Entrepreneurship	Seattle, WA	Aug 2010	Korean-American Scientist and Engineers Association
International Conference on Renewable Energy (ICRE 20111)	Jaipur, India	Jan 2011	Centre for Non-Conventional Energy Resources, University of Rajasthan
Colorado Rural Electric Association	Denver, CO	Feb 2010	CREA
Global New Energy Summit,	Colorado Springs, CO	Apr 2011	
IEEE International symposium on Power Line Communications	Udine, Italy	Apr 2011	IEEE
Americas session, 7th Invitational International Symposium on Microgrids	Jeju Island, South Korea	May 2011	IISD
Smart Grid R&D Workshop	Golden, CO	May 2011	DOE, EERA
IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing,	San Juan, Puerto Rico	Dec 2011	IEEE
IEEE PES 16th International Conference on Intelligent system Applications to Power Systems,	Hersonissos, Greece	Sep 2011	IEEE
IEEE Smart Grid Vision Project focusing on Vehicles, Smart Grid, and Intelligent Transportation Systems	Washington DC	Oct 2011	IEEE
2011 IEEE Energy Conversion Congress and Exposition (ECCE),	Phoenix, AZ	Sep 2011	IEEE
Colorado Renewable Energy Society 15th Annual Conference	Fort Collins, CO	Jun 2011	CRES
ASME 2011 5th Annual Energy Sustainability Conference	Washington DC	Aug 2011	ASME
Power Systems Engineering Research Center (PSERC) Future Grid Initiative Workshop held at the,	University of California-Berkeley	Dec 2011	PSERC
IEEE PES Conference on Innovative Smart Grid Technologies (ISGT)	Washington, DC	Jan 2012	IEEE
International Symposia on Micro Grids	Évora, Portugal	Sep 2012	
IEEE Power & Energy Society (PES)	San Diego,	Jul 2012	IEEE

Table 7 Conference Participation			
Name of Conference	**Location of Conference**	**Date of Conference**	**Conference Sponsor**
General Meeting,	CA		
IEEE Military Communications Conference	Orlando, FL	Oct 2012	IEEE
ASME 2012 Energy Sustainability Conference	San Diego, CA	Jul 2012	ASME
IEEE PES International Conference on Power Systems Technology (POWERCON12),	Auckland, New Zealand	Nov 2012	IEEE
23rd International Conference on Database and Expert Systems Applications (DEXA 2012)	Vienna, Austria	Sep 2012	DEXA

*Note limited foreign travel was covered under this grant, travel covered by other grants

Networks or Collaborations Fostered

Numerous collaborations and expert networks have been fostered under the SGIL grant and include the following professional organizations, industries, universities, and city, state, and federal entities.

a. IEEE Power & Energy Society
b. IEEE Energy Conversion Congress
c. National Science Foundation
d. Xcel Research Foundation
e. Power Systems Engineering Research Center
f. NREL
g. Colorado Clean Energy Cluster
h. University of Minnesota
i. Spirae
j. Siemens
k. City of Fort Collins
l. Fort Zed DOE Project
m. ARPA-E
n. Colorado State Governor's Energy Office on Smart Grids

Other products

Electric Power Engineering: Introduction to power system market Operations

Funding Expenditures

Funding of $874,800.74 has been expended against charges of $874,800.74 for this project.