Final Scientific / Technical Report

SMART GRID INTEGRATION LABORATORY

DOE Prime Contract Award: DE-OE-0000070
DOE Project Officer: Thomas J. George

Recipient: Colorado State University

Principal Investigator: Wade Troxell

12/22/11

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-OE-0000070 which will be used for teaching, experimentation, and testing of Smart Grid Technology.

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Executive Summary:

The initial federal funding for the Colorado State University Smart Grid Integration Laboratory is through a Congressionally Directed Project (CDP), DE-OE0000070 Smart Grid Integration Laboratory. 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 initial phase of staff acquisition which was directed and administered by DOE NETL/ West Virginia under Project Officer Tom George. 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 will be 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 10/1/2009 to 9/30/2011 which included one no cost extension due to time delays in faculty hiring.

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. Using the results of 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 has been used to guide the hiring of faculty, program curriculum and education plan. This project develops 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 Contract:

a. Support of Faculty and SGIL development
b. Hiring of 2 Faculty
c. Creation 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 12 Conferences
f. Partial Development of the Smart Grid Boot Camp Course
g. Smart Grid Curriculum Offering
h. Eight (8) publications

Comparison of 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:

- Organize the formation of a Smart Grid Integration Laboratory
- Conduct a national search to identify top faculty candidates in smart grid integration and making a global impact
- Hire up to three smart grid faculty members to tenure track positions
- Develop a smart grid systems integration education roadmap
- Develop one smart grid course

The contract's project objectives follow suite as described below:

- Provide the formation for the Smart Grid Integration Lab in the College of Engineering at Colorado State University with the vision of being a world leader in smart grid integration and making a global impact in smart grid innovations and technologies.
- Conduct a hiring process for Smart Grid Systems faculty
- Hire faculty that will develop curricula, tech classes, and conduct research in smart grid integration
- Survey the field of smart grid industry needs and develop a plan for educating a smart grid workforce.
- Develop a framework and a set of courses to educate a smart grid workforce.
- Develop the content for one course.

We have met these goals as referenced in Table 1. Over 90 applications were received for the three faculty positions. These were down selected to 11 applicants for on-campus interviews. Though offers have been made, it has been difficult finding qualified candidates. CSU has just recently confirmed the hiring the third faculty member, a mechanical engineering professor, after contract end. Findings from a separately funded Smart Grid Workforce Education Workshop held May 2009 before funding of the actual contract (December 2009) were used to guide the program curriculum and education plan, as well as requirements from expert new faculty members. Two Smart Grid professional courses were created 1) Microgrid as a Foundation for Smart Grid Education funded by CSU cost share, and 2) Smart Grid BootCamp. Four graduate engineering courses have been offered as part of a Smart Grid Curriculum as shown in Table 8. Eight publications were written by the professors as shown in Table 6.

Table 1 Objectives and Outcomes Summary of SGIL Phase 1	
Objective / Goal	**Outcome**
1. Provide the formation for the Smart Grid Integration Lab (SGIL) in the College of Engineering (COE) at Colorado State University (CSU) with the vision of being a world leader in smart grid integration and making a global impact in smart grid innovations and technologies. **Goal:** Organize the formation of a SGIL	Status: **Met.** The SGIL was established at the CSU COE Engines and Energy Conversion Laboratory building in 2010.
2. Conduct a hiring process for Smart Grid Systems faculty. **Goal:** Conduct a national search to identify top faculty candidates in smart grid integration and making a global impact	Status: **Met**. Hiring processes were conducted for 2 electrical engineering professors and for 1 mechanical engineering professor.
3. Hire faculty that will develop curricula, tech classes, and conduct research in smart grid integration. **Goal:** Hire up to three SGIL faculty	Status: **Met.** Two globally known electrical engineering professors or experts in smart grid systems integration were hired from among 90+ applicants. Although offers were made for a mechanical professor in smart grid systems integration, a hire was unsuccessful until after this contract's end.
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

CSU is developing a Smart Grid Integration Center (SGIC) to lead the transformation of the U.S. electric power grid from a central power generating station model to more distributed use of renewable power generation sources and active coupling the demand side, i.e., the end users. The InteGrid Laboratory is located in the repurposed Fort Collins Power Plant and the partners include the City of Fort Collins Utilities, Spirae, and the Northern Colorado Clean Energy Cluster. This effort is in response to the unrelenting pressure to move to a post-fossil fuel energy infrastructure, the desire for energy independence, and the need to transition to the U.S. electric power infrastructure with a larger percentage of renewable energy resources while being more secure and resilient to natural and manmade disasters. The InteGrid Laboratory supports the development and testing of the next generation of "smart grid" technologies utilizing the combination of CSU's unique facilities and expertise, enabling leading edge "smart grid" systems research coupled with economic development for Colorado and the U.S.

The formation of the SGIC is in response to the national need to reduce U.S. dependence on foreign oil, create jobs, and help U.S. industry compete successfully in global markets for clean energy technology. The SGIC is to provide the platform for education and industry training while supporting research that furthers public and private partnerships. The SGIC mission is "to train industry, educate 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." See Figure 1. It is projected that annually $5M in new sponsored research will be produced when fully operational.

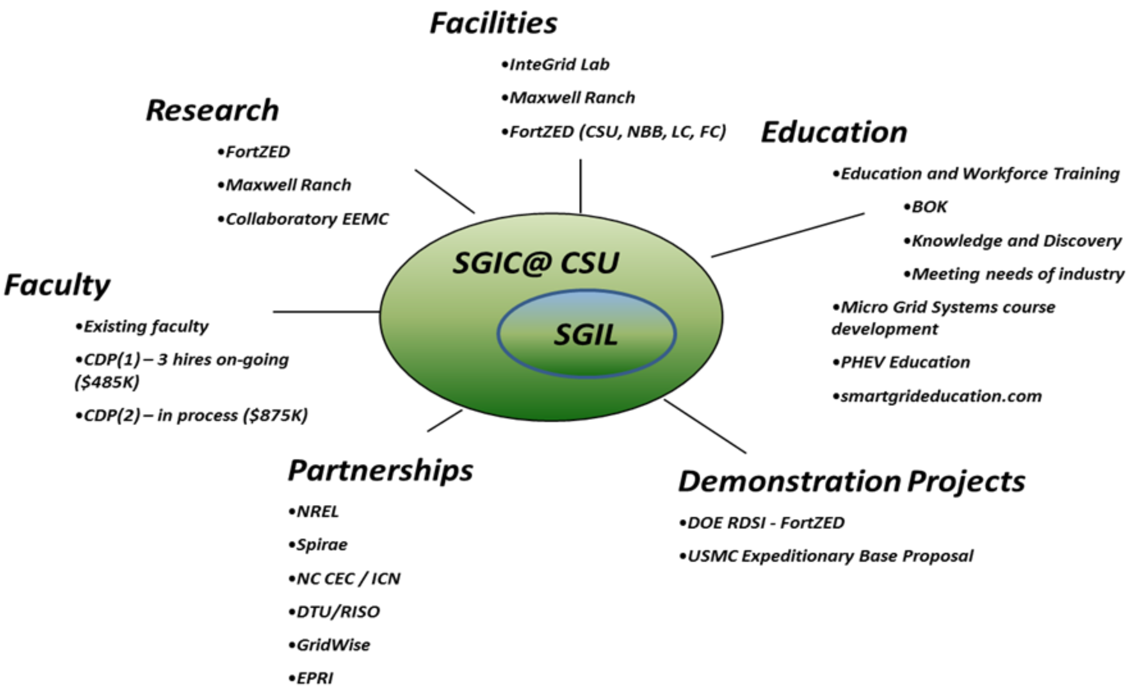

Figure 1 CSU Smart Grid Integration Center and Laboratory

The Smart Grid Integration Laboratory (SGIL) will be 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 is a crucial and integral part of the SGIC, will have capabilities 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 core technologies for enabling them to be used in a distribution utility network remain very limited and not well understood.

Task 2 Faculty Hiring

The standard CSU faculty hiring process was followed by the SGIL Faculty Search Team as shown in Figure 2. The SGIL Faculty Search Committee Team consisted of members as shown in Table 2.

Table 2 CSU SGIC Faculty Search Committee Team

Name	Organization	Program Role
Wade Troxell	CSU COE	PI, Search Committee Chair; Assoc. Dean/Assoc. Professor
Dan Zimmerle	CSU COE InteGrid Laboratory	Education Developer/Research Associate
Anita Montgomery	CSU Office of Sponsored Programs	CSU Contracts Administrator
Peter Young	COE Electrical and Computer Engineering	Assoc. Prof
Tom Bradley	COE Mechanical Engineering	Assist. Prof
Neil Grigg	COE Civil and Environmental Engineering	Full Professor
Ron Sega	COE Electrical and Computer Engineering	Full Professor, VP for Energy and the Environment, CSURF, CSU
Judy Dorsey	Northern Colorado Clean Energy Cluster;	Adjunct Prof ME CSU/ Dean's Advisory Board Member / Part of interview team

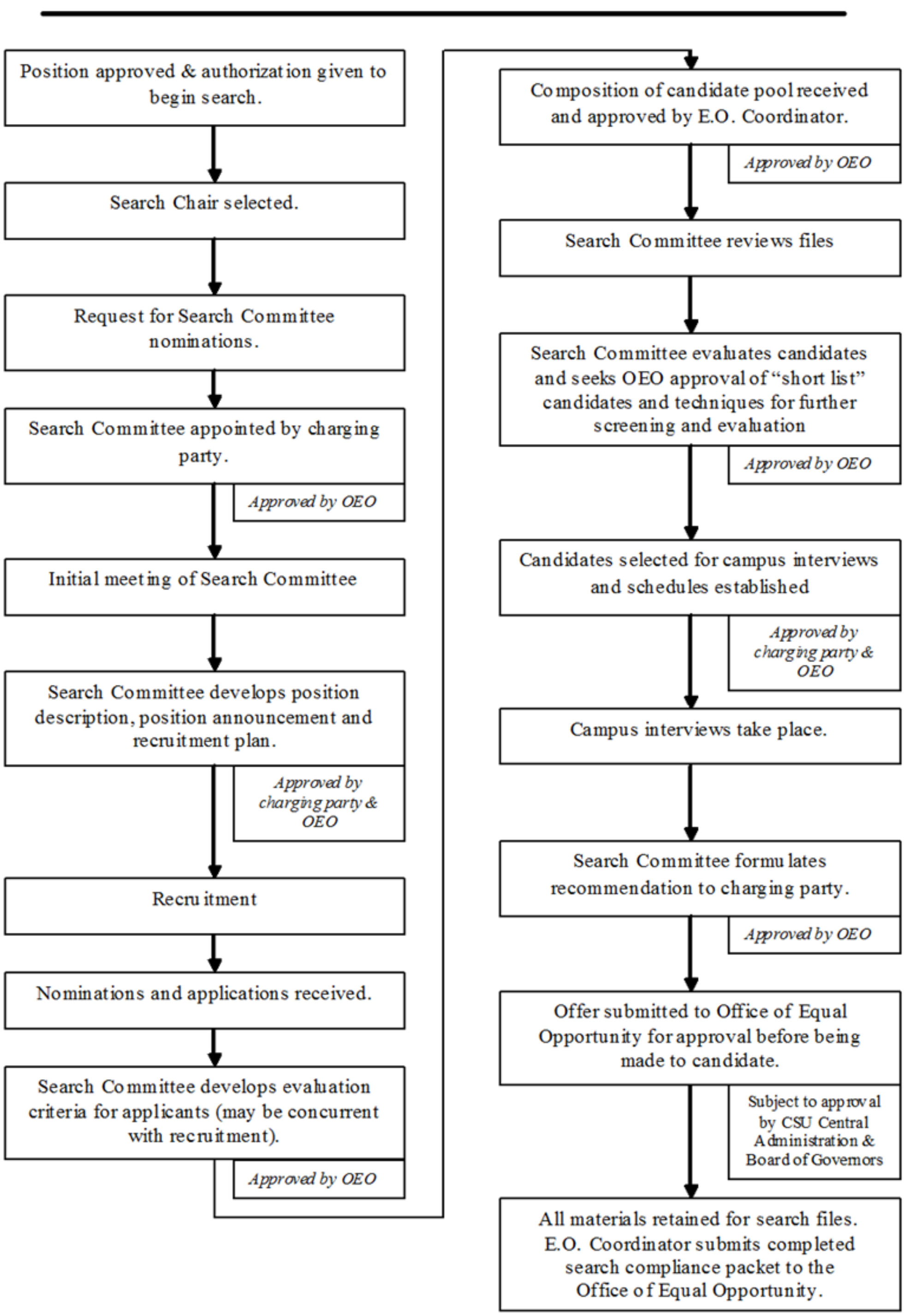

Figure 2: CSU Hiring Process

Over 90 applicants were reviewed as part of the initial hiring notice. This process is quite lengthy and was a schedule constraint. Two very well-known electrical engineering professors were hired, Dr. S.

Suryanarayanan and Dr. L. Yang. Difficulty in finding an appropriate mechanical engineering recruit has proven difficult and resulted in hiring schedule delays and cost share 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 3.

Table 3 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
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
TBD	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 4.

Table 4 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

Table 4 SGIL Advisory Board Members		
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

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 will be offered on-site at National Renewable Energy Lab (NREL) and 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

Two course outlines were developed for the initial course work: Fundamentals of Micro-Grid and Renewable Energy in Island Power Systems per the needs identified by industry. 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, was also partially funded under this grant and will be delivered in Phase 2. The course outlines for each university course are included 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. 1^{st}-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 with the exception of 1 course is the focus of the next Phase 2 part of the SGIL funded in separate grant. Course Delivery Methods are identified in Table 5.

Table 5 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

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.	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
2.	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
3.	X. Chen, F. Qu and L. Yang, "OFDM-IDMA for Power Line Communications," in Proceedings o International Symposium on Power Line Communications and Its Applications, Udine, Italy, April 3-6, 2011
4.	H. E. Brown, S. Suryanarayanan, G. T. Heydt, "Some characteristics of emerging distribution systems under the Smart Grid Initiative," Elsevier The Electricity Journal, vol. 23, no. 5, pp. 64-75, Jun 2010.
5.	P. Zhao, S. Suryanarayanan, M. G. Simões, "A conceptual scheme for cyber-physical systems energy management in building structures," in Proc. 9th IEEE/IAS International Conference on I Applications (IndusCon), São Paulo, Brazil, Nov. 2010.
6.	P. Zhao, S. Suryanarayanan, M. G. Simões, "An energy management system for building structures using a multi-agent decision-making control methodology," in Proc. 2010 IEEE Industry Applications Society Annual Conference, Houston, TX, Oct. 2010.
7.	S. Suryanarayanan, R. K. Rietz, J. Mitra, "A framework for energy management in customer-microgrids," in Proc. 2010 IEEE Power & Energy Society (PES) General Meeting, Minneapoli Jul 2010.
8.	S. Suryanarayanan, P. F. Ribeiro, M. G. Simões, "Grid modernization efforts in the USA and Brazil – Some common lessons based on the Smart Grid Initiative, in Proc. 2010 IEEE Power & Energy Society (PES) General Meeting, Minneapolis, MN, Jul 2010.

*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
Colorado Rural Electric Association	Denver, CO	Feb 2010	CREA
Smart Grid R&D Workshop	Golden, CO	May 2011	DOE, EERA
IEEE International symposium on Power Line Communications	Udine, Italy	Apr 2011	IEEE

*Note no foreign travel was covered under this grant, only salary

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

New CSU Smart Grid Curricula Offered

The four courses in Table 8 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 8 Smart Grid Courses Offered		
Professor	**Smart Grid Courses**	**Offered**
Yang	Spread Spectrum Communications	Fall 2010
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

Other products

None