

**San Diego Gas & Electric
Microgrid Performance Simulation Project**

**Submitted by
Christina Cheek
Mulugeta Damamo
D'Angelo Woods**

**Senior Design
April 20, 2010**

Microgrid Performance Simulation Project

We certify that this is an accurate Final Report and we are in agreement that this report is an accurate representation of the project

Name	Signature	Date
-------------	------------------	-------------

Name	Signature	Date
-------------	------------------	-------------

Name	Signature	Date
-------------	------------------	-------------

I certify that this report is an accurate representation of the project and I approve it.

Advisor's/Instructor's Name	Signature	Date
------------------------------------	------------------	-------------

Executive Summary

A microgrid is a small-scale version of the power grid that can operate autonomously or in parallel with the grid. Our project focuses on proving the concept of a microgrid while also analyzing the cost and benefits associated with implementing such a system. Following the lead of those who have developed their own microgrid and evaluated the results of such a system, Team SMART was successful in simulating the performance of a system that maintained operation under islanded conditions and fully integrated renewable energy resources (RERs) thus helping to reduce carbon emissions. We were also successful in executing our design requirements while adhering to all relevant constraints and industry standards.

Table of Contents

Introduction	6
Problem Definition	8
Current Status of Art	8
Design Requirements	10
Solution Generation and Selection of Top Solution	11
Implementation of Top Design	13
Performance Analysis and Evaluation of the Project	17
Conclusion and Recommendations	18
References	19
Appendix	22

Introduction

With the dawn of the 21st century comes the realization that the nation's three major interconnected power grids are aging. There exists a need for an improved system that meets the demands of today's customers while also having a better impact on the environment.

In 2007, the Energy Independence and Security Act was established in response to the increased demand for electricity and the appeal of environmentally-friendly energy resources. The purpose of this policy was to decrease our dependence on foreign oil and to produce green and cost-efficient power from renewable energy resources (RERs), which offer zero to low greenhouse gas emission (GHGs). Individual distributed generators (DG) utilizing RERs are already in place but they can be optimized using a microgrid. Microgrids are small-scale versions of the larger interconnected grid and involve DGs supplying low-level voltage (LV) electricity from RERs. Using this system, consumers can generate electricity in their own backyard to meet their electrical demand with the option of selling excess electricity to their energy providers through incentive programs. The microgrid consists of information-based technologies that have the potential to increase asset utilization and reliability, optimize the design of circuit operations, operate more cost-effectively and reliably, and improve the security and reliability of electricity supply of the present power grid. Before the Microgrid project can be fully implemented, however, there must be proof that the Microgrid will indeed operate as described.

The first step in proving the concept of the microgrid was the development of specific criteria which would be added to our design requirements. The next step involved a search and evaluation of various software packages that would adhere to our constraints while meeting our design requirements. This search resulted in us selecting several packages with which to implement our design including Power Systems Computer-Aided Drafting (PSCAD), Power Systems Analysis Toolbox (PSAT), and the MATLAB/Simulink Environment with the SimPowerSystems Toolbox. However, a software package developed by the National Renewable Energy

Laboratory (NREL) known as HOMER, or Hybrid Optimization Model and Electric Renewables, proved to be our most optimum choice due to its ease of use, availability, and expanded features. After the selection of our simulation package, we were able to move forward with our cost/benefit and carbon emission analysis, which were all able to be executed using the HOMER software.

Several of our undergraduate courses proved useful in completing this project. Our Senior Design course provided the foundation upon which our initial design was established. The textbook utilized within our Power Communication and Control course was an invaluable resource in gaining knowledge about renewable energy, maintenance and reliability, and hazard function graphs. In our consideration of probabilistic methods through which to evaluate component failure, we referenced our notes from the aforementioned course as well as Probability and Random Variables.

San Diego Gas and Electric (SDG&E) served as our sponsor and provided us with our external advisor, Dr. Tom Bialek. SDG&E is a California-based utility company that provided electricity and natural gas to 3.3 million customers throughout San Diego and Orange County. Representatives from SDG&E have made several visits to the campus of Howard University to render presentations on their operations as well as to recruit interns and employees for their company.

Problem Definition

The purpose of our project is three-fold: We seek to prove the concept of the microgrid, analyze its costs and benefits, and the emissions produced by such a system. To prove the concept, we will show that the microgrid works under normal and faulted conditions and how it can be modeled. We determine how much it will cost to design and implement the microgrid and determine the benefits to SDG&E and its customers. We also analyze the microgrid's effect on the environment by showing how much carbon emissions are reduced by its use.

Current Status of Art

The concept of a microgrid is one that has sparked interest within both the public and private sector. Many of these projects are funded by the United States Department of Energy and most are in collaboration with local, state, and federal utilities. Team SMART has isolated three of these projects from which to learn and adopt new ideas that can benefit us in achieving our objectives. These projects are listed below:

CEC/DOE Energy Storage Collaboration

When we speak of microgrids, we must discuss one of their most important functions, which is the ability to isolate loads from the main power grid. Storage capabilities are crucial during isolation because it withholds power that can be distributed locally for uninterrupted service. According to the project's website, this project will demonstrate the use of an ultra capacitor energy storage module in support of a selection of distributed energy resources that could potentially be configured as an electric microgrid. The California Energy Commission and the U.S. Department of Energy is sponsoring the project in order to (1) evaluate the ability of the energy storage system to improve power quality for the facilities critical loads, and (2) to demonstrate the

ability of the energy storage system to isolate part of the facility without shutting down any of the critical equipment during the transition from the grid to the backup generator.

CERTS Microgrid Test Bed Demonstration with AEP

Demonstrated at a full-scale test bed outside Columbus, Ohio, the Consortium for Electric Reliability Technology Solutions (CERTS) sought to reduce the amount of custom engineering required for integrating renewable energy options into the microgrid. As a result, the microgrid avoids many of the current concerns associated with integrating DER, such as how many DER the system can tolerate before their collective electrical impact begins to create problems like excessive current flows into faults and voltage fluctuations. This will help the Team evaluate the practicality, costs, and emissions associated with implementing renewable energy resources into the microgrid. This project was also successful in that the electrical protection system was able to distinguish between normal and faulted operation, conditions under which the Team will also need to simulate and test.

SDG&E Beach Cities Microgrid Project

San Diego Gas & Electric's (SDG&E) project was used as a guide for the Team as we completed similar objectives. The Beach Cities Project involves a proof-of-concept and cost/benefit analysis, as well as a greater than 15% feeder peak load reduction requirement. While SDG&E's project will involve incorporating advanced sensors, controls, and communications, our focus is mainly on the concept itself and how much it would cost.

Constraints and Design Requirements Technical (Standards, Regulation and Rules)

- Microgrid must operate as a stand-alone system
- Minimize costs associated with design, implementation, and maintenance of microgrid system for customer and SDG&E
- Achieve at least 15% reduction in feeder peak load through the integration of RERs
- Reduce carbon emissions
- Microgrid must operate under normal and faulted conditions
- Microgrid must be modeled, simulated, tested, and evaluated within a software-computing environment

Standards	Applications
IEEE 1547	Physical and electrical interconnections between utility and distributed generation (DG)
IEEE 1686-2007	Security for intelligent electronic devices (IEDs)
NERC CIP 002-009	Cyber security standards for the bulk power system
NIST Special Publication (SP) 800-53, NIST SP 800-82	Cyber security standards and guidelines for federal Information systems, including those for the bulk power system
Open Automated Demand Response (Open ADR)	Price responsive and direct load control
OpenHAN UtilityAMI 2008 HAN SRS	Home Area Network device communication, measurement, and control
ZigBee/HomePlug Smart Energy Profile	Home Area Network (HAN) Device Communications and Information Model

Table 1. Standards

Solution Generation and Selection of Top Design

Hybrid Optimization Model for Electric Renewables (HOMER)

HOMER was created by the National Renewable Energy Laboratory (NREL) in 1993. According to the HOMER Energy website, HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation (DG) applications. This type of evaluation will prove useful in satisfying our proof-of-concept design requirement. During disturbances the generation and corresponding loads can separate from the distribution system to isolate the microgrid's load from the disturbance, also known as going off-grid (Lasseter). HOMER will also assist our cost/benefit analysis through its optimization and sensitivity analysis algorithms that will allow us to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables.

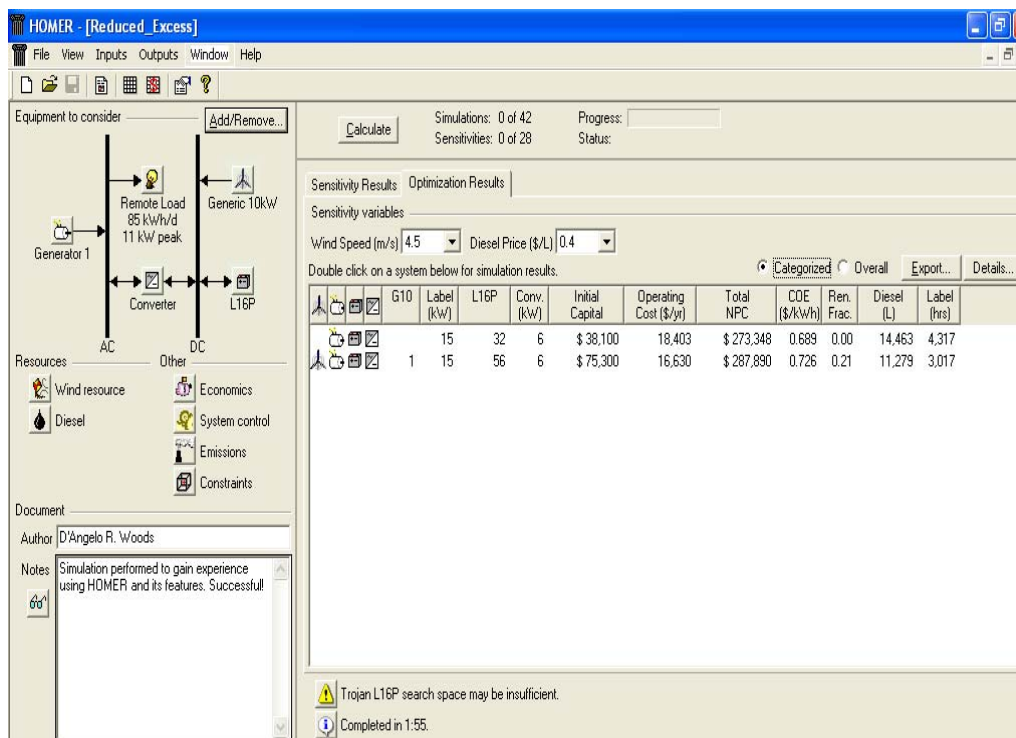


Figure C. Preliminary Schematic using HOMER. This particular simulation was able to choose from among several options the most cost-feasible combination of components and displays the optimal choices. Note the lower overall price is associated with the system that does not include a wind turbine.

C++ (Visual Studio)

Another possible approach is to write a program in C++ to do all of the tasks requested. In order to prove the microgrid concept, it will utilize a database of information relevant to San Diego Gas & Electric to provide the most accurate representation of the area in which the Microgrid will be implemented. The program will also use this data to calculate costs and to determine how much greenhouse gas emissions are reduced. All DGs will be modeled mathematically using their respective equations.

This approach differs from the main approach because it requires us to code the entire program. It will be an all-in-one program rather than using various programs to achieve our results. Another difference in this approach is the fact that we are utilizing a database to provide the information about the system. In our main approach, we will be entering data individually into the program, but using this approach, such data entry will be automated. Though this approach may be more difficult and time-consuming, the benefit is that we can essentially write the program to cater to our needs.

PSCAD

The SimPowerSystems toolbox is an extension of the Simulink environment and allows for the modeling and simulation of power systems including the generation, transmission, and distribution of these systems. Most of the team will be gaining extensive experience using the MATLAB/Simulink software this semester through our Linear Control Systems course. However, additional time will be needed to familiarize ourselves with the SimPowerSystems toolbox. This toolbox contains a multitude of helpful features such as the ability to automatically generate differential equations that characterize our system as well as the ability to interconnect with blocks created in Simulink. However, it is the financial aspect of this software that introduces the need for re-evaluation. It is currently priced at \$3000. A full-access version of our alternative software package, PSCAD/EMTDC, is provided through its website at no cost to us. It is also able to perform the modeling, simulation, and analysis using a single, graphical interface.

Comparing the Solutions

		Possible Solutions							
		1		2		3		4	
Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Feasibility	45	3	135	2	90	1	45	3	135
Cost	30	3	90	4	120	1	30	4	120
Ease of Use	15	2	30	4	60	1	15	3	45
Advisors' Opinion	10	TBD		TBD		TBD		TBD	
Total Rank		255		270		90		300	

Legend	
1	Original
2	C++ (Visual Studio)
3	Physical Model
4	PSCAD

Figure D. Decision Matrix

Below are the selection criteria that were used to develop our decision matrix:

- Feasibility: ease of implementation
- Cost: total cost of implementation
- Ease of use: practicality for customer
- Advisors' opinion: input from advisors

Despite the high score given to the PSCAD option, we realized that the software would actually be very time-consuming in terms of learning how to use it. With our time constraints in mind, we decided that our best choice was to use HOMER for our simulations and to compile our findings into a MS Excel spreadsheet.

Implementation of the Top Design

The final results of our HOMER simulations were both interesting and informative. However, these results were not arrived at easily. The Team had many concerns and faced several difficulties when using the NREL-developed. We were unprepared for the amount of data that was actually required by HOMER and that was

required to be entered manually. For example, solar resource and wind data, solar radiation, latitude and longitude of our target area, and detailed component information needed to be researched and compiled before adequate results could be obtained. Perhaps the greatest challenge was securing load profile information for our target area. The difficulties associated with securing the load profile information stem from the fact that specific data is not publicly available. Initially the Team researched and compiled information for a single household. As can be seen in our screenshot below, the peak load for a system with parameters defined for a single household was 1.8kW. This seemed rather low when considering the holistic approach that our project was to undertake. Using these numbers would have required assumptions to have been made that may have tarnished the integrity of the project.

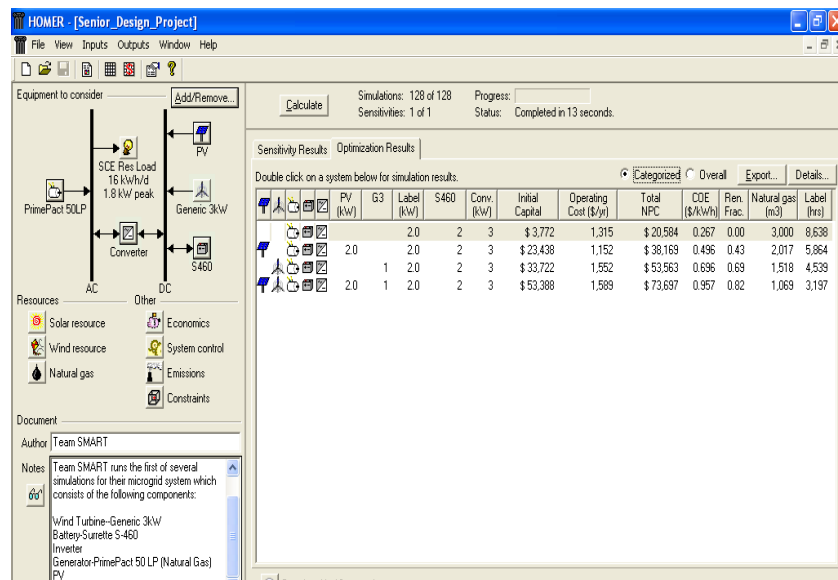


Figure E. HOMER Simulation Results for One Household. Notice an average output of 16 kWh/d.

To alleviate this issue, we refined our searching methods by targeting load profile information for the entire area served by SDG&E. This too presented problems because the peak load associated with the load profile information for an area of that magnitude required us to utilize components with very high parameters. HOMER warned us that no feasible solutions could be found due to maximum annual capacity shortage constraints. These constraints consisted of the maximum percentage of unmet load that we would allow. Since our

microgrid was required to not only meet the load demand but to reduce its peak by greater than fifteen percent, we decided to take another approach. The final approach was to utilize load information for a smaller area in California that would allow us to proceed with our simulations and provide as accurate results as possible. As explained earlier in our report, Borrego Springs, CA was chosen as our area due the vast amount of potential for solar energy as well as the fact that it is an area currently being used by SDG&E to test its own microgrid technologies.

Since we needed the residential load profile for the Borrego Springs area as opposed to all of the SDG&E residential customers, we had to determine a scaling factor to accurately calculate the load profile for Borrego Springs. This was done by using the ratio of occupied households in Borrego Springs (1,163) to the total number of SDG&E Residential customers (3.3 million).

Ratio of Borrego Springs Residents to SDG&E Customers: $\frac{1163}{3.3E6} = 3.524E - 4$

This scaling factor was multiplied by each of the values in the load profile to establish the load profile for Borrego Springs, the targeted area. The load profile for Borrego Springs, CA is shown below. (A detailed chart is shown in the appendix.)

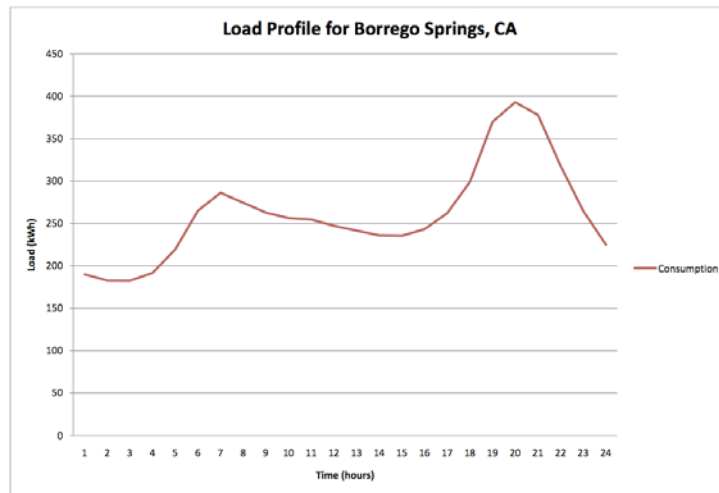


Figure F. Load Profile for Borrego Springs, CA

After selecting our appropriate components, we were ready to begin our simulations.

The results of our HOMER simulation were highly informative and allowed us to observe graphs and charts that could be easily interpreted. HOMER performed over one-thousand simulations of various configurations using our data as input. It categorized these simulations into those that were the most economically feasible. In our past experiments with HOMER, the most economically feasible solution was not always the “cleanest” solution in regard to carbon emissions. In our final results, however, the configuration chosen by HOMER was also the configuration chosen by the Team to be most beneficial in terms of cost and carbon emission. Our appendix shows detailed results of these simulations.

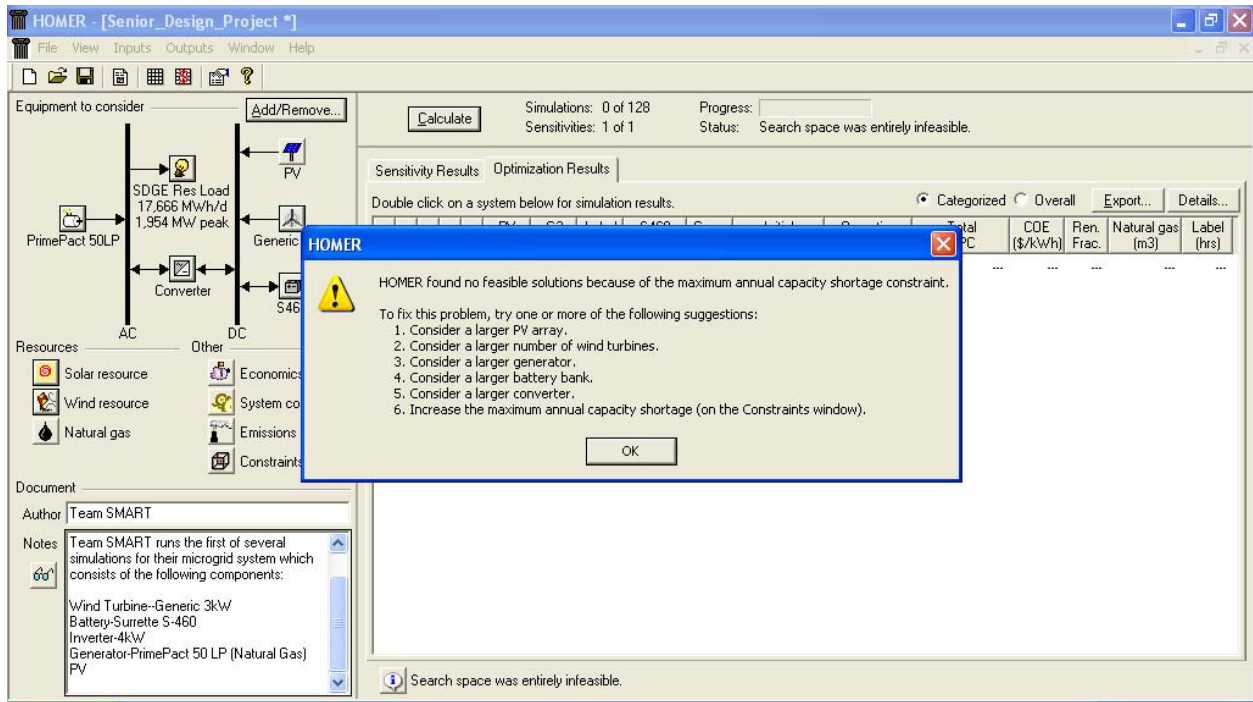


Figure G. Result of Using Load Profile Information for Entire SDG&E Service Area

Performance Analysis/ Evaluation of the Project

As mentioned earlier, HOMER provided us with the most economically feasible configurations that best matched our input data. Our default configuration consisted of a system that included an inverter, natural gas generator, PV array, battery, and wind turbine. Parameters such as the size, cost, and quantity of the component were defined within HOMER. The results of our simulations are below:

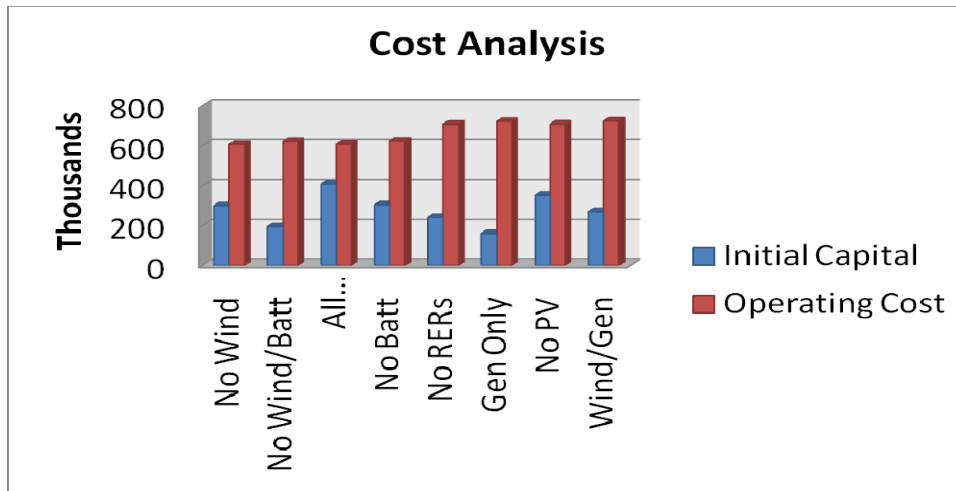


Figure H. Cost Analysis for our Microgrid

The initial capital was measured alongside the operating cost of each configuration and placed into Excel to produce our graph. It is important to note that “No Wind” or “No RERs” simply means that the particular configuration consisted of all of the components excluding that particular component. This was helpful in that it allowed us to view the results of the system that did not include a specific component. The absence of a particular component could be the result of a fault in the system and our Team defined this as a faulted condition. Therefore, we were able to conclude that our microgrid system could indeed operate under both normal and faulted conditions.

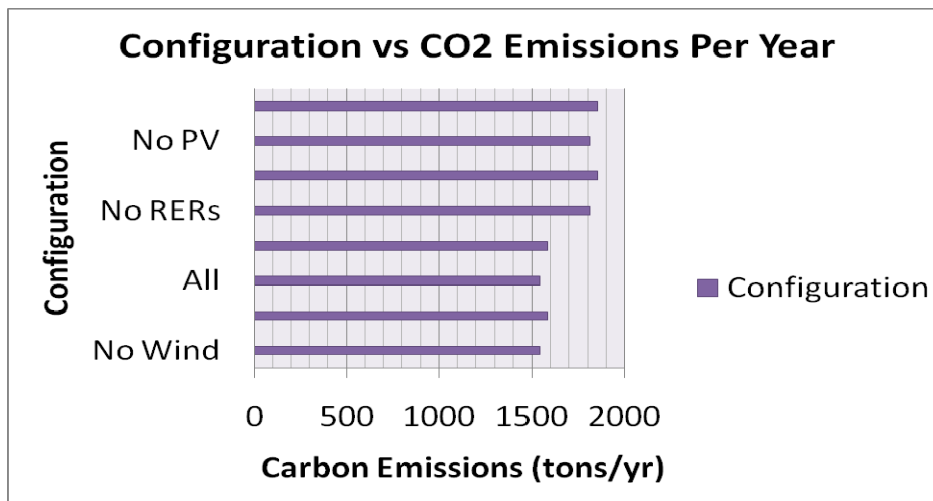


Figure I. Configuration vs. Carbon Emissions per Year

The results of our carbon emissions analysis showed that while the configuration that utilized all of our components produced the same amount of CO₂ as the system that contained no wind turbine, it was less expensive to configure the system that utilized one less component. There would be no wind turbine but the solar PV array would be used and it has zero emissions. Other results from our simulations and project can be found in the appendix of this report. HOMER rates the amount of carbon emitted in terms of kilograms per year. We converted this number into tons per year in order to provide a more practical unit of measurement.

Conclusion and Recommendations

As our results show, we were able to successfully prove the concept of the microgrid. The microgrid was able to supply the load under both normal and faulted conditions and we found that HOMER was an excellent tool for modeling the microgrid. Based on our data, we determined that the cheapest implementation of the microgrid was a system that did not utilize wind turbines. Each configuration of the microgrid that used RERs has the potential to produce excess electricity, therefore giving the customer the opportunity to earn money by selling this unused power back to the main grid. One of the greatest benefits of the microgrid was the reduction in carbon emissions produced in the Borrego Springs area. It is recommended by our team that further research be conducted not only in the field of distributed automation for the microgrid concept but also in software tools that are available to perform such studies. This project introduced the team and our classmates to NREL's HOMER and it proved to be an invaluable tool due mostly to its user-friendly interface. However, HOMER has been around since 1993 and is only one of several software-in-the-loop techniques that can be employed by those who find themselves conducting experiments such as the one described in this report. Tools such as NEPLAN, DISREL, and PSAT are readily available for student-use within Howard University's Center for Energy and Control Systems, headed by the author of a textbook used as a reference for this project, Dr.

James Momoh. Future work could also include modeling of the microgrid system within other software environments for additional analyses.

References

- NREL.HOMER.<https://analysis.nrel.gov/homer/>. 3 November 2009.
- San Diego Gas & Electric. Smart Grid. San Diego Gas and Electric Company.
<http://www.sdge.com/smartgrid/> 1 November 2009.
- F. D. Kanellos, A. I. Tsouchnikas, N. D. Hatziargyriou. June 2005. Micro-Grid Simulation during Grid-Connected and Islanded Modes of Operation.
http://www.ipst.org/TechPapers/2005/IPST05_Paper113.pdf. 27 March 2010
- Momoh, James. Electric Power Distribution, Automation, Protection, and Control. Boca Raton, FL: Taylor & Francis Group, 2008.
- DOE Pulse. Innovative combinations push NREL's analysis to new levels 26 July 2004.
http://www.ornl.gov/info/news/pulse/pulse_v163_04.htm. 3 April 2010.
- T. Lambert, P. Gilman, P. Lilienthal. Micropower System Modeling with HOMER.
<http://www.mistaya.ca/software/docs/MicropowerSystemModelingWithHOMER.pdf>.
3 April 2010.
- List of U.S.States by carbon dioxide emissions. 2 February 2010.
http://en.wikipedia.org/wiki/List_of_U.S._states_by_carbon_dioxide_emissions. 6 April 2010
- <http://www.docstoc.com/docs/9960451/Power-system-reliability> 6 April 2010
- Customer Load Profiles. <http://www.sdge.com/esp/electricEspCustomerLoadProfiles.shtml>. 9 April 2010.
- WSS Select Grid Tie Systems. <http://www.wholesalesolar.com/>. 9 April 2010.
- Sunrise Powerlink. 5 April 2010. http://en.wikipedia.org/wiki/Sunrise_Powerlink. 12 April 2010.
<http://www.city-data.com/housing/houses-Borrego-Springs-California.html>. 12 April 2010.

Appendix

Final Design Requirements

- Microgrid must operate as a stand-alone system
- Minimize costs associated with design, implementation, and maintenance of microgrid system for customer and SDG&E
- Achieve at least 15% reduction in feeder peak load through the integration of RERs
- Reduce carbon emissions
- Microgrid must operate under normal and faulted conditions
- Microgrid must be modeled, simulated, tested, and evaluated within a software-computing environment

Design Project Proposal

**San Diego Gas & Electric
Microgrid Simulation Project**

Submitted by

**Christina Cheek
Mulugeta Damamo
D'Angelo Woods**

Approved by

Proposal Review Panel Representative:

Name

Signature

Date

Senior Design I Instructor:

Name

Signature

Date

Introduction

With the dawn of the 21st century comes the realization that the nation's three major interconnected power grids are aging. There exists a need for an improved system that meets the demands of today's customers while also having a better impact on the environment.

In 2007, the Energy Independence and Security Act was established in response to this increased demand for electricity and the desire for more environmentally friendly energy sources. The purpose of this policy was to be independent of foreign oil and produce green and cost-efficient power from renewable energy resources (RERs). RERs are tremendous and offer limited greenhouse emission. Individual distributed generators (DG) utilizing RERs are already in place but they can be optimized using a microgrid. Microgrids are small-scale versions of the larger interconnected grid and involve DGs supplying low-level voltage (LV) electricity from RERs. Using this system, consumers can generate electricity in their backyard and use it for their property or sell it to the utility company. In cases of disturbances, the microgrid can operate independently of the power grid and reconnect after The San Diego Gas & Electric (SDG&E) Microgrid Project was initiated to develop such a system. The Microgrid consists of information-based technologies that have the potential to increase asset utilization and reliability, optimize the design of circuit operations, operate more cost-effectively and reliably, and improve the security and reliability of electricity supply of the present power grid. Before the Microgrid project can be fully implemented, there must be proof that the Microgrid will indeed operate as described.

To adequately meet this need, it is the responsibility of Team SMART to provide a clear assessment of the cost and benefit of such technologies as well as a proof-of-concept of the Microgrid under both normal and faulted conditions. The technical background required for these tasks include basic circuit analysis, power systems analysis, and programming/simulations experience, specifically in MATLAB and power simulation tools. It is also necessary for the Team to be capable of analyzing the correlation between the cost and benefit of the Microgrid as well as providing an accurate evaluation of its environmental impact through an emissions analysis.

The goal of the SDG&E Microgrid Project is to have advanced grid technologies in place by 2020 that will facilitate a 30% reduction in greenhouse gas emissions, which includes supplying 33% of their customers' energy needs from renewable energy sources. The Team's goal is to assist SDG&E with their goals by proving the microgrid concept, evaluating the costs of such a system, evaluating the performance of the system under normal and faulted conditions, and performing a carbon emissions analysis by March 2010.

Problem Definition

Our project seeks to prove the concept of a "microgrid," while also analyzing the cost and benefits associated with implementing such as system. Following the lead of those who have developed their own microgrid and evaluated the results of such a system, Team SMART will focus on simulation of the system under normal and faulted conditions. To accomplish this we will have to design our system so that it is able to differentiate between a normal and faulted condition, maintain operation under islanded conditions, fully integrate renewable energy sources that help to reduce carbon emission, and comply with specific regulations.

Constraints

- Minimize costs associated with design, implementation, and maintenance of microgrid system for customer and SDG&E
- Achieve >15% reduction in feeder peak load

- Project must be modeled, simulated, tested, and evaluated within a software-computing environment.

Compliance/Regulations

There are several on-going projects that are progressing toward establishing standards and regulations specific to the microgrid concept. One of these standards is the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems which established criteria and requirements for interconnection of distributed resources with electric power systems.

A more detailed definition will be provided as more information becomes available through our external advisors.

Current Status of Art

The concept of a microgrid is one that has sparked interest within both the public and private sector. Many of these projects are funded by the United States Department of Energy and most are in collaboration with local, state, and federal utilities. Team SMART has isolated three of these projects from which to learn and adopt new ideas that can benefit us in achieving our objectives. These projects are listed below:

CEC/DOE Energy Storage Collaboration

When we speak of microgrids, we must discuss one of their most important functions which is the ability to isolate loads from the main power grid. Storage capabilities are crucial during isolation because it withholds power that can be distributed locally for uninterrupted service. According to the project’s website, this project will demonstrate the use of an ultra capacitor energy storage module in support of a selection of distributed energy resources that could potentially be configured as an electric microgrid. The California Energy Commission and the U.S. Department of Energy is sponsoring the project in order to (1) evaluate the ability of the energy storage system to improve power quality for the facilities critical loads, and (2) to demonstrate the ability of the energy storage system to isolate part of the facility without shutting down any of the critical equipment during the transition from the grid to the backup generator.

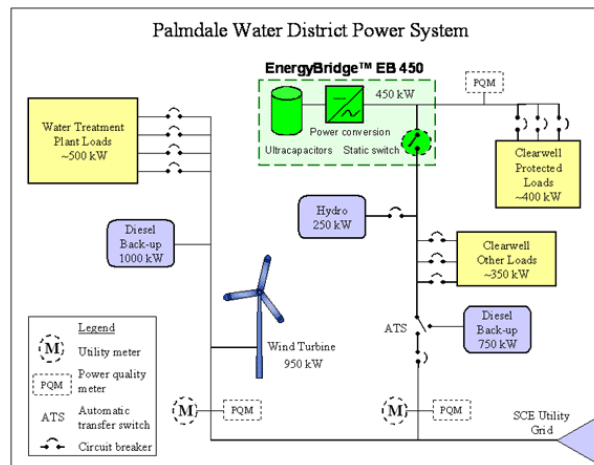


Figure E. Palmdale Water District Power System

The Team will not only gain knowledge of energy storage systems and how they relate to improved performance of a microgrid but will also be able to take advantage of the project’s real-time analysis and ability to reduce peak load, thus satisfying one of our constraints. The costs and benefits involved with incorporating the zinc bromine battery based storage system will also be helpful in evaluating the economical feasibility of a microgrid system.

CERTS Microgrid Test Bed Demonstration with AEP

Demonstrated at a full-scale test bed outside Columbus, Ohio, the Consortium for Electric Reliability Technology Solutions (CERTS) sought to reduce the amount of custom engineering required for integrating renewable energy options into the microgrid. As a result, the microgrid avoids many of the current concerns associated with integrating DER, such as how many DER the system can tolerate before their collective electrical impact begins to create problems like excessive current flows into faults and voltage fluctuations. This will help the Team evaluate the practicality, costs, and emissions associated with implementing renewable energy resources into the microgrid. This project was also successful in that the electrical protection system was able to distinguish between normal and faulted operation, conditions under which the Team will also need to simulate and test.

SDG&E Beach Cities Microgrid Project

San Diego Gas & Electric's (SDG&E) project will be used as a guide for the Team as we complete similar objectives. The Beach Cities Project involves a proof-of-concept and cost/benefit analysis, as well as a greater than %15 feeder peak load reduction requirement. While SDG&E's project will involve incorporating advanced sensors, controls, and communications, our focus will be on the concept itself and how much it would cost. Tom Bialek, Chief Engineer for the Beach Cities Project, will also be contacted for additional assistance as we move forward with our project.

Engineering Approach

Our project will consist of constructing a small-scale power system using the SimPowerSystems toolbox within our MATLAB/Simulink environment for analysis and testing. All necessary data as it relates to our power system should be obtained through these simulations. We will need to develop various conditions under which the system's operation will be observed. Using our PSAT software we will be able to run our simulations repeatedly using normal and faulted conditions. With the HOMER software, we can model our microgrid and analyze the costs and benefits of several configurations (see Figure C). The various faulted conditions could include:

- Balanced and Unbalanced Load Flow
- Connection and Disconnection of Loads (Figure A)
- Faults in the Sources
- Faults in Loads
- Islanding Conditions

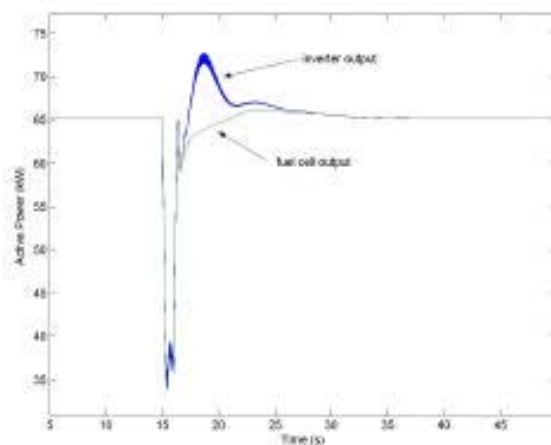


Figure A. shows the results of a disconnection of a 70 kW active load, followed by its reconnection

1 second later under islanding conditions. Source: <http://www.microgrids.eu/micro2000/presentations/6.pdf>

We will also implement knowledge gained through projects that have been and are currently being performed by other entities and compare their results with the results that we get from our own testing. HOMER will allow us to enter relevant information in order to perform our cost/benefit analysis of the microgrid system. Integration of distributed energy resources and energy storage capabilities have been covered by other projects (i.e. CERTS Microgrid concept) and this information will be used to calculate associated costs and benefits as it relates to our design. When more information becomes available through our external advisors, we will adjust our approach accordingly including alternative solutions.

Team SMART has collective experience in Network Analysis, Energy Conversion, and Power Systems Analysis courses. Specific topics from these courses include:

- Kirchoff's Voltage and Current Laws
- One-Line Diagrams
- Distributed Generation
- Three-Phase Systems
- Renewable Energy Resources

In addition to the above topics, the Team will seek to gain more knowledge in power systems analysis and simulation tools and power electronics. These courses will allow us to take a holistic approach to power systems while still being able to use simple concepts to perform specific calculations.

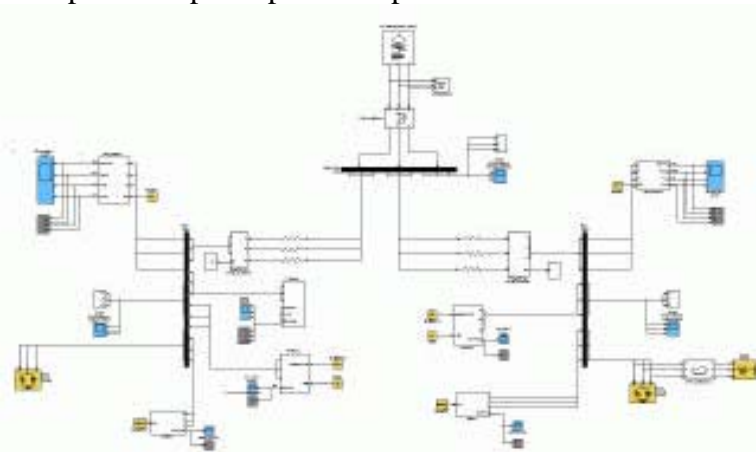


Figure B. shows an example of a balanced operation model developed in a MATLAB/Simulink environment.

Source: <http://www.microgrids.eu/micro2000/presentations/6.pdf>

Because the main objective of our project is to model, simulate, and analyze a microgrid system, we will need to explain the rationale for using these software tools, highlighting their functions and how they will assist us in completing our short-term and long-term goals.

Hybrid Optimization Model for Electric Renewables (HOMER)

HOMER was created by the National Renewable Energy Laboratory (NREL) in 1993. According to the HOMER Energy website, HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation (DG)

applications. This type of evaluation will prove useful in satisfying our proof-of-concept design requirement. During disturbances the generation and corresponding loads can separate from the distribution system to isolate the microgrid's load from the disturbance, also known as going off-grid (Lasseter). HOMER will also assist our cost/benefit analysis through its optimization and sensitivity analysis algorithms that will allow us to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables. This is seen in Figure C.

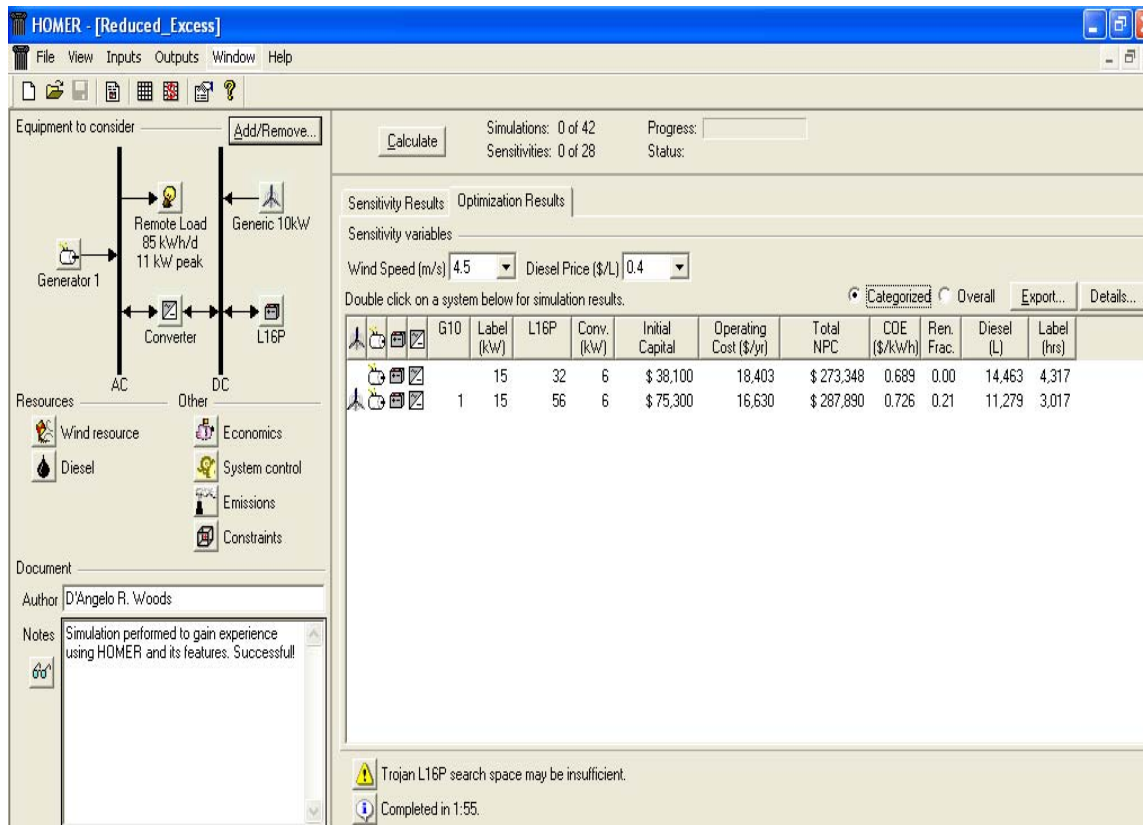


Figure C. Preliminary Schematic using HOMER. This particular simulation was able to choose from among several options the most cost-feasible combination of components and displays the optimal choices. Note the lower overall price is associated with the system that does not include a wind turbine.

Each team member will download HOMER and perform sample simulations in order to become acquainted with the software.

SimPowerSystemsAnalysis 5.2

The MathWorks, creator of the MATLAB and Simulink environments, defines the SimPowerSystems software as a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. The toolbox will work with our MATLAB/Simulink software as an add-on to model electrical, mechanical, and control systems which will be useful in modeling our microgrid and evaluating its operation under normal and faulted loads.

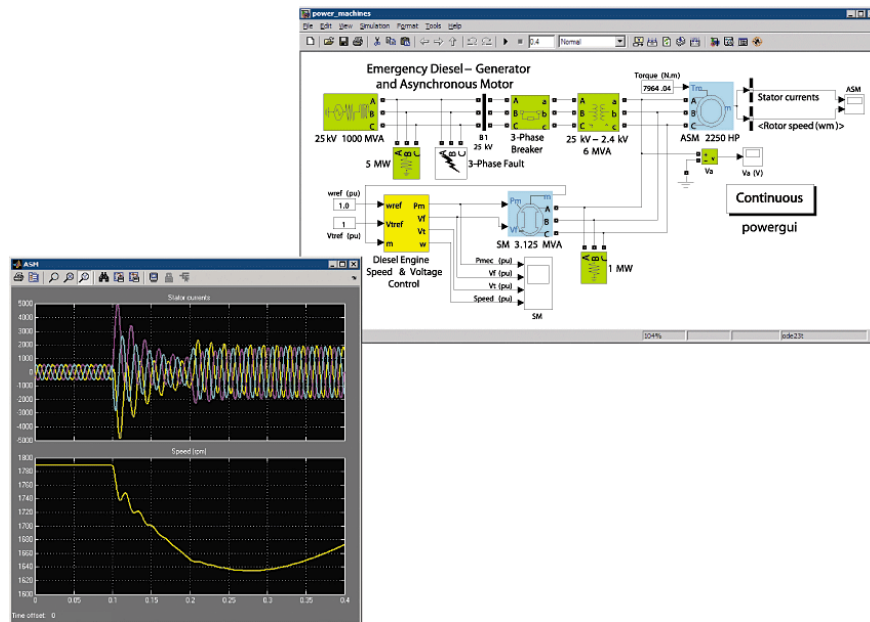


Figure D. SimPowerSystems Model of an Asynchronous motor and Diesel-generator Uninterruptible Power Supply (UPS)

MATLAB/SimuLink

“MATLAB® is a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and Fortran,” according to its product page on The MathWorks website. The MATLAB environment presents us with a programming atmosphere that is conducive to generating code that is compatible and that will control our Simulink models. Simulink allows users to model, simulate, and analyze dynamic systems and from it we can build our model either from scratch or from existing models. The MathWorks also mentions that we can use the sensor blocks in SimPowerSystems to measure current and voltage in our power network, and then pass these signals into standard Simulink blocks. Source blocks enable Simulink signals to assign values to the electrical variables current and voltage. Sensor and source blocks allow us to connect a control algorithm developed in Simulink to a SimPowerSystems network. All of our team members have experience generating code and plots using MATLAB and thus time will be saved when performing any relevant tasks with the software.

Power Systems Analysis Toolbox (PSAT)

PSAT was developed by Federico Milano as an electric power system analysis and control toolbox that is compatible with MATLAB. The use of PSAT is necessary especially for our faulted conditions. Fault analysis, harmonic analysis, and protection analysis tools are currently unavailable from MATLAB packages and toolboxes. PSAT will allow us to perform optimal power flow analysis on our system and serve as a useful toolbox to use with our Simulink environment for conditional analyses. Because our MATLAB package does not contain tools for fault analysis, PSAT will serve us well when simulating under faulted conditions.

Project Management

Timeline and Milestones

Assignment	Deadline
Proposal Presentations	November 13, 2009

Written Proposals: Version II	November 18, 2009
Full Design Proposals	November 20, 2009
Final Proposals	December 2, 2009
Team Evaluations	December 2, 2009
Peer Evaluations	December 2, 2009
Team Binder	December 2, 2009
Evaluation/Selection of Design	December 14, 2009
Simulation, Testing, and Re-Evaluation	January 18, 2010
Final Design	February 15, 2010

Task Assignments

Because we believe that every member of this team is a leader, we have not assigned a team leader. However, to organize and optimize the Team's efforts and activities, each team member was assigned roles in accordance with their special skills and abilities. These roles are as follows:

- Christina Cheek will develop and prepare our mathematical models for simulations.
- Mulugeta Damamo will perform our carbon emissions analysis.
- D'Angelo Woods will obtain information from SDG&E for component specifications and to establish feeder peak load baseline.
- All team members will conduct research of microgrid concept and use simulation tools to acquire data.

Deliverables

- Microgrid Model
- Report on Microgrid Operation Under Normal/Faulted Conditions
- Microsoft Excel Spreadsheet of Cost/Benefit Analysis
- Emissions Analysis Report

Ethics

As stated in our Team contract, we will adhere to the ethical standards set forth by the Institute of Electrical and Electronic Engineers, which are as follows:

1. to accept responsibility in making decisions consistent with the safety, health and welfare of the public and the Howard University community, and to disclose promptly factors that might endanger the Howard University community, public, or environment ;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding of technology, its appropriate application, and potential consequences;
6. to maintain and improve our technical competence and to undertake technological tasks for our internal and external advisors only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;

10. to assist colleagues and fellow students in their professional development and to support them in following this code of ethics.

In addition to these standards, each team member shall maintain a positive attitude towards his/her teammates, external and internal advisors, classmates, company sponsors, and administrators.

Budget

Our tentative budget for this project is presented below:

Item	Description	Cost	Total Cost
MATLAB/Simulink Student Version	MATLAB is a numerical computing environment and fourth generation programming language. Developed by The MathWorks, MATLAB allows matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages (MATLAB)	\$99.00	
SimPowerSystems Toolbox	SimPowerSystems™ extends Simulink® with tools for modeling and simulating the generation, transmission, distribution, and consumption of electrical power. It provides models of many components used in these systems, including three-phase machines, electric drives, and libraries of application-specific models such as Flexible AC Transmission Systems (FACTS) and wind-power generation.(SimPowerSystems 5.2)	\$59.00 (add-on product)	
Hybrid Optimization Model for Electric Renewables (HOMER)	HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables	\$0.00	
Power Systems Analysis Toolbox (PSAT)	The Power System Analysis Toolbox (PSAT) is a MATLAB toolbox for electric power system analysis and simulation. The main features of PSAT include: Power Flow; Continuation Power Flow; Optimal Power Flow; Small Signal Stability Analysis; Time Domain Simulation; Phasor Measurement Unit (PMU) Placement; Complete Graphical User Interface; User Defined Models; FACTS Models; Wind Turbine Models	\$0.00	
Miscellaneous Expenses	Funds that may be used to cover the costs of miscellaneous items, etc.	\$200.00	\$358.00

In addition to these products, the Team will also need to acquire a computer workstation on which to operate this software. This workstation will be either one offered by the College of Engineering or that of one of the Team members at no cost to the Team.

Conclusion

To recapitulate, the need for the revamp of the nation's energy infrastructure has never been so evident. With the emergence of renewable energy generators in homes has become a dire need for a system such as the microgrid to serve as an intelligent interface between individually distributed generators and utility companies. Prior to the complete implementation of the microgrid, it must be proven that the system will operate effectively under both normal and faulted conditions while being cost-effective for both the utility company as well as its customers. The benefit of the project is that the microgrid's advantages and areas for improvement will be determined prior to full implementation, saving time and money for San Diego Gas & Electric and its customers.

As stated before, the Team plans on utilizing MATLAB, HOMER, and PSAT for simulating the power system in normal and faulted conditions. The simulations of faulted conditions should include load problems, islanding issues, and faults in sources. This approach will be refined as more information about the Team's responsibilities is revealed.

The cost of the project should be no more than \$300, including necessary software and other needs. By December 2009, the Team will have developed both the Implementation and Evaluation Plans for the project. The final product will be completed and evaluated by March 2010.

References

CERTS. CERTS Microgrid Test Bed at American Electric Power. Consortium for Electric Reliability Technology Solutions (CERTS). <http://certs.lbl.gov/certs-derkey-mgtb.html> 1 November 2009.

EPRI. Micro Grid Energy Storage Demonstration. CEC/DOE Energy Storage Collaboration. <http://energystoragedemo.epri.com/cec/microgrid/microgrid.asp> 1 November 2009.

Kim, Charles, Ph.D. Senior Design Class 2008-2009. EECE401 Senior Design I/EECE404 Senior Design II. 1 November 2009. http://www.hirstbrook.com/SD0809/DFL_PROP.pdf

Mathworks, The. SimPowerSystems 5.2. 1994-2009. <http://www.mathworks.com/products/simpower/>. 3 November 2009.

MATLAB. 2 November 2009. <http://en.wikipedia.org/wiki/MATLAB>. 3 November 2009.

Milano, Frederico. PSAT. <http://www.power.uwaterloo.ca/~fmilano/psat.htm>. 3 November 2009.

NREL.HOMER. <https://analysis.nrel.gov/homer/> . 3 November 2009.

San Diego Gas & Electric. Smart Grid. San Diego Gas and Electric Company. <http://www.sdge.com/smartgrid/> 1 November 2009.

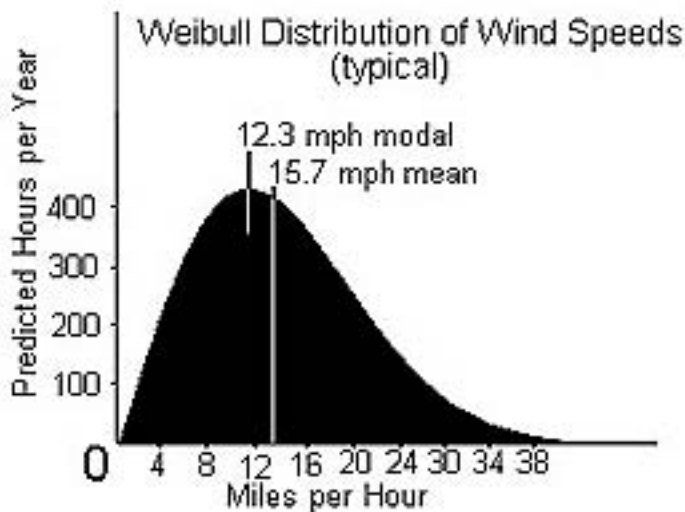
The Mathworks. <http://www.mathworks.com/access/helpdesk/help/toolbox/physmod/powersys/ug/f10-51564.html> 8 November 2009.

Dr. P. Lilienthal. The HOMER® Micropower Optimization Model. January 2005. <http://www.nrel.gov/docs/fy05osti/37606.pdf> 8 November 2009. Dr. P. Lilienthal

Attachments

The following information will be used to assist in the carbon emissions analysis of the microgrid:

1. April 22, 2009 Mike Chrisman, Chair and Members California Ocean ...
File Format: PDF/Adobe Acrobat - Quick View
Calculate annual CO2 emission rate for reuse, non-potable source:
SDG&E assigns a CO2 emission rate of 915 lb per MW-hr (or 0.915 lb per kWh) for ...
www.opc.ca.gov/.../RKII%20Desal%20Letter%20to%20OPC.Final.pdf
2. <http://www.otherpower.com/windbasics1.html>
The statistics used to calculate the distribution of wind speeds are complicated, but the results are easy to understand. In most locations worldwide, the distribution of wind speeds keeps fairly close to a Weibull or (simplified) Rayleigh distribution of wind speeds, shown below. There are non-Rayleigh locations where the curve takes on other shapes, but these are relatively rare. The distribution shown here is relatively common.



In the chart, the horizontal axis shows wind speed, and the vertical axis the probability (which can be condensed down to the predicted number of hours per year) that the wind is blowing at that speed. The area under the graph is always equal to one, because the probability that the wind is either blowing or not blowing is always 100%.

If we use a 10-foot (3.048 m) diameter rotor for a 7.30 m² swept area in a 10 mph wind, we get:

Power available (Watts)

$$= \frac{1}{2} * 1.23 * 7.30 * 4.4704^3$$

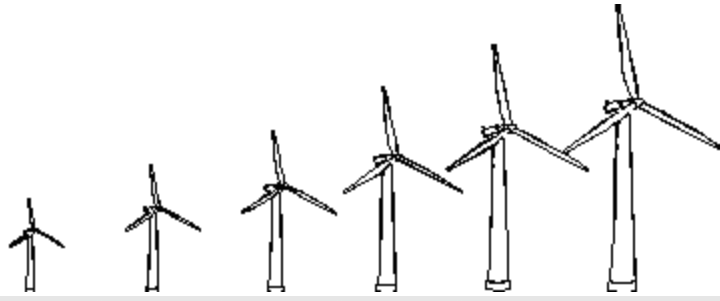
** =

401 Watts

3)

http://www.awea.org/faq/wwt_basics.html

Wind turbines vary in size. This chart depicts a variety of historical turbine sizes and the amount of electricity they are each capable of generating (the turbine's capacity, or power rating).



	1981	1985	1990	1996	1999	2000
Rotor (meters)	10	17	27	40	50	71
Rating (KW)	25	100	225	550	750	1,650
Annual MWh	45	220	550	1,480	2,200	5,600

The electricity generated by a utility-scale wind turbine is normally collected and fed into utility power lines, where it is mixed with electricity from other power plants and delivered to utility customers. Today (August 2005), turbines with capacities as large as 5,000 kW (5 MW) are being tested.

4) from source 1,2 and 3

We can calculate how much CO₂ is reduced by our project

From (3): using a 5 MW wind turbine,

From (2): average wind below 12.3 mph for 400hrs a year

We can generate:

$$\text{Energy} = P \cdot t = 5\text{MW} \cdot 400\text{hrs} = 2000\text{MWh annually}$$

So we can reduce:

From (1) and (4):

$$915 \text{ lb per MWh} \cdot 2000 \text{ MWh} = 1830000 \text{ lb of CO}_2 \text{ per year from a single wind turbine}$$

One wind turbine needs 0.008178 sq. mile to plant

If we use 1% of SDG&E covered area (4100 sq. mile) to implement wind turbines, we can plant 5013 wind turbines (source: Scientific American , Nov. 2009)

$$4100 \cdot .01 = 41 \text{ sq. mile we can plant 5013 wind turbines}$$

So we can generate:

$$5013 \cdot 2000\text{MWh} = 10026 \text{ GWh}$$

So using 1% of a covered area by SDG&E, we can reduce

$$915 \text{ lb per MWh} \cdot 10026000 \text{ MWh} = 9.17379 \text{ trillion lb. per year from SDG\&E area; which is good for SDG\&E and its customers.}$$

END OF PROPOSAL

HOMER Input Data

Load Profile for Borrego Springs, CA

Hour	Load (kW)
00:00 - 01:00	190.000
01:00 - 02:00	182.630
02:00 - 03:00	182.380
03:00 - 04:00	191.730
04:00 - 05:00	219.320
05:00 - 06:00	264.930
06:00 - 07:00	286.040
07:00 - 08:00	274.400
08:00 - 09:00	262.730
09:00 - 10:00	256.200
10:00 - 11:00	254.480
11:00 - 12:00	247.080
12:00 - 13:00	241.480
13:00 - 14:00	236.040
14:00 - 15:00	235.570
15:00 - 16:00	243.230
16:00 - 17:00	262.090
17:00 - 18:00	298.770
18:00 - 19:00	369.630
19:00 - 20:00	392.900
20:00 - 21:00	377.910
21:00 - 22:00	317.900
22:00 - 23:00	264.740
23:00 - 00:00	225.050

Resource Data

	Quantity	Capital	Replacement	Sizes to consider	Slope (PV Only)	Type	Lifetime	Efficiency
PV	1	\$29,500	\$29,500	3kW, 4kW, 4.9kW	32°			
Battery	1	\$523.40	\$523.40	2.10kWh (20hr)		Surrette S-46	10 years	
Converter	1	\$2,600	\$2,600	3kW, 4kW*, 6kW			10 years	95%
Generator	1	\$1,939		4.5kW, 5kW*		Primepac 50L	20 years	
Wind Turbine	1	\$29,950	\$29,950	3kW*, 5kW		Generic 3kW		95%

	Wind
Time period	Wind speed (mph)
January	6
February	6.6
March	7.5
April	7.8
May	7.9
June	7.8
July	7.6
August	7.4
September	7.1
October	6.5
November	5.9
December	5.6
Annual	7

Solar	
Longitude	Latitude
32° 44' N	117° 10' W

Cost of Natural Gas
\$0.23/m ³

Resumés

Objective

To get challenged internship, while completing my studies in Electrical Engineering.

Education

- **Howard University, Washington DC**
B.S. Electrical Engineering
Expected Graduation: December 2010
Cumulative **GPA**: 2.54 on a 4.0 scale
- **University of Maryland College Park**
Engineering Science
Aug – Dec 2006
- **University of Maryland Eastern Shore Princess Ann, Md**
Sep 2005 – Aug 2006
Engineering Science

Experience

- **Super Fresh, White Oak Md** Jun 2005 till present
- **Summer internship, University of Maryland Eastern Shore** Summer 2006
- Worked with Ass. Professor to help high school students to improve their academic performance during their summer time and advised them to think about their future after they graduate high school.
- Contributed to the program's Retention Excellence Award.

Achievements / Activities

- National Society of Collegiate Scholars Apr 2008 till present
- Awarded achievement certificate at University of Maryland Easter Shore for Summer internship program Jun 2006

Skills

- Basic computer skill including C++, Matlab
- Identifying, reading and measuring basic electric circuit elements
- Basic theoretical and laboratory knowledge of major electrical courses

Permanent U.S. Residence

D'Angelo R. Woods
rashadwoods@gmail.com
(313) 618.9293

Current Address:
2251 Sherman Ave., NW #417B
Washington DC 20001

Permanent Address:
9520 Dalton Drive
Belleville, Mi 48111

EDUCATION

Howard University, Washington DC
B.S. in Electrical Engineering
May 2010

Expected

RELEVANT COURSEWORK

Energy Conversion Power Communication & Control Introduction to Linear Algebra Network Analysis I and II
Electronics I,II Economics Differential Equations Introduction to Programming Power Systems Analysis Senior
Design I and II

EXPERIENCE

Federal Service Student Ambassador, Department of Energy: Howard University, Washington, DC (August 2009 – Present)

- Tasked to develop and execute meetings, events, and presentations in order to assist students with discovering and applying for internships within the Department of Energy
- Organized event to bring Senior Energy Analyst of U.S. DOE Solar Technologies Program to campus to render presentation to students
- Awarded for creating best slogans for Partnership for Public Service give-a-ways

Intern, Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC (June 2009 – July 2009)

- Selected from over 50 interns to evaluate nominations for the 2009 Federal Energy and Water Management Awards
- Created a Federal Energy Usage Guidebook and Task Orders Assignment Book to assist federal employees with energy management
- Chosen to work with mechanical engineer in conducting an experiment using Spectrally-Enhanced Lighting to collect data that will influence implementation in federal buildings and increase energy and cost savings

Research Assistant, Howard University, Washington, DC (June 2008 – July 2009)

- Tested and operated solar heat panel unit while collecting data
- Developed a temperature controller model using LabView and dSPACE hardware and software
- Co-authored paper, "Heating System Supervisory Control for Residential Energy Conservation," 2009
- Presented paper at the 2009 ASME 3rd Annual Conference on Energy Sustainability in San Francisco, CA

Machine Operator, Kelly Services: Pall Life Sciences, Ann Arbor, Mi (June 2006 – August 2006)

- Manually assembled purification, filtration, and separation filters
- Analyzed and solved mechanical errors with on-site manufacturing engineers

Mathematics/Personal Development Teacher's Assistant, L.I.F.E. Academy, Ann Arbor, Mi (June 2005 – July 2005)

- Administered lessons in mathematics, spelling, and reading to over 50 elementary school children
- Supervised students at lunch and recess
- Awarded "Funniest Facilitator" by students

PROFESSIONAL AFFILIATIONS/ACTIVITIES

Institute of Electrical and Electronics Engineers (IEEE): Student Member
National Society of Black Engineers (NSBE): Student Member
Department of Energy Student Ambassador
Howard University Marching Band: Trumpet Section Leader 2006-2008
Kappa Kappa Psi National Honorary Band Fraternity, Incorporated: Secretary, Vice President of Membership
Senior Design Project: Microgrid Performance Simulation, Team Lead

COMPUTER SKILLS

Applications: LabView, MATLAB, PSPICE, Mobile Studio, SimuLink, Microsoft Office (Word, Excel, Power Point)

Languages: Microsoft Visual C++

Operating Systems: Windows XP/Vista