Department of Electrical and Computer Engineering
Howard University
Washington, DC 20059

Senior Design
April 23, 2014

Integration of Distributed Generation to the Power Grid: Sirius Power

Submitted By:
Phathom Donald

EECE404 Senior Design II
Electrical and Computer Engineering
Howard University
Instructor: Dr. Charles Kim

Integration of Distributed Generation to the Power Grid: Sirius Power

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**

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

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

Acknowledgements

Special thanks are extended to Tiago Costa for initiating the project and offering assistance throughout its development. I would also like to thank Dr. James Momoh for providing lectures and documents on HOMER and distributed generation technology.

Executive Summary

Utility consumers have generally been subject to considerable costs for electric service, including that obtained from natural gas. Central generation is the electrical power production by central station power plants that provide bulk power. Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power, thereby requiring fewer transport services of the transmission and distribution networks. A number of these consumers, who rely on central generation, do not know of the benefits of distributed generation, let alone the best distributed generation technology that can be used to meet their needs. The program, Sirius Power, successfully takes customer and utility data and outputs the financial return of the most economical distributed generation method that serves the customer’s electricity needs. The design requirements where successfully executed while adhering to all relevant constraints and the program has the potential to be expanded for even greater use.

Table of Contents

I. Background of the Project

Utility consumers have generally been subject to considerable costs for electric service, including that obtained from natural gas. A number of these consumers, who rely on central generation, do not know of the benefits of distributed generation, let alone the best distributed generation technology that can be used to meet their needs. Central generation is the electrical power production by central station power plants that provide bulk power.[1] Large central generators feed electrical power up through generator transformers to a high voltage transmission network. The transmission system is used to transport the electrical power, often over considerable distances, and it is then passed down through a series of distributed transformers to final circuits for delivery to customers. By the time electricity has reached the end consumer the relative 'value' and price of electricity has increased. This increase in the value of electricity is driven primarily by the added cost of network transmission and distributed services imperative for the delivery of power from central generators to customers elsewhere in the network.[2]

Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power, thereby requiring fewer transport services of the transmission and distribution networks.[3] Distributed generation involves delivering power to demand at an equivalent value to that of central generation, with the costs of using the network being avoided. Generating power on-site, rather than centrally, eliminates the cost, complexity, interdependencies, and inefficiencies associated with transmission and distribution. There are multiple types of distributed generation: solar, wind, fuel cells, internal combustion engines, microturbines, steam turbines, etc.

II. Problem Formulation & Current Status of Art

The goal of this project is to develop a model that will take customer data and output the financial return of the most economically efficient distributed generation method for meeting the customer's electricity needs. The model will take this data output the financial return for the customer based on the selected distributed generation technology, electric utility, and system size. The team's combined skills in engineering economics and power distribution acquired from earlier courses and work experiences play a major role in the problem formulation and problem solution.

In terms of current status of art, HOMER Energy is a micro-grid modeling software for designing and analyzing hybrid power systems, which contain a mix of conventional generators, combined heat and power, wind turbines, solar PV, batteries, fuel cells, hydropower, biomass and other inputs.[5] For either on-grid or off-grid environments, HOMER helps determine how variable resources such as wind and solar can be optimally integrated into hybrid systems. The model also permits comparison between the results to get a realistic projection of capital and operating expenses, including the economic feasibility. HOMER is a complete model but it is not an Excel-based system and it does not take into account government incentives

III. Constraints and Technical Design Requirements

System	Description
Functionality	◆ Perform economic calculations and output user's avoided cost and yearly cash flow.
User Interface	◆ Allow user to specific electric utility, system technology, and system size. ◆ Allow user to export cash flow data to spreadsheet.
Capabilities	◆ Perform calculations based on built-in database of utility rate structures and government taxes.
Others	◆ **Accessible to any operation system.** ◆ **Ease of use (Can be used on personal computer).**

The model will analyze the inputted data thoroughly and output the financial return of the desired method for distributed generation. The goal is to minimize the cost of electric service by means of distributed generation, which is subject to constraints pertaining to the resources available to the customer. For instance, while distributed generation by means of solar energy is the main focus of this project, the model must consider the possibility of little solar energy being available to the costumer because of their location.

IV. Solution Generation & Selection of Top Design

Microsoft Excel Model

The first solution approach consisted of two stages. The first stage is the simulation and optimization of the distributed generation system inside the HOMER software. The second stage is the financial analysis in a model in the form of an excel spreadsheet. The user would input the results of the HOMER simulation, as well as other factors into the excel spreadsheet. This approach was very reasonable because Microsoft Excel allows users to perform economical calculations with built-in functions. However, the user interface of this model is very overwhelming which could potentially deter users from using it.

Sirius Power

The second approach was to replace the Microsoft Excel model with a computer program that would be coded in C++. This approach allows for a better, less overwhelming user interface. However, there is still added complexity to the design and development of the program and there was concern that completion of the program would be delayed.

Decision Design Matrix

	Weight	Design 1	Score	Total Score	Design 2	Score	Total Score
Functionality	5	Microsoft Excel	3	15	Computer Program	4	20
Ease of Use	4	Complex User Interface	3	12	Simple User Interface w/ Instructions	5	20
Complexity in Development	3	Added Inputs	3	9	Complete Redesign	2	6
Convenience	2	Works in Excel	5	10	Download Program	4	8
Cost	1	Must Purchase Excel	3	3	No/Little Purchase Necessary	4	4
Total				49			58

The second approach was chosen as the top design, which still involves two stages. The main objective of the first stage is to simulate the first year of operation for each DG system, then, calculate the energy avoided cost, the maintenance and fuel costs, if applicable. In order to do that, there are inputs to be inserted in HOMER. The first being the utility rate structure, then the customer hourly load for one year, the technology specifications such as fuel consumption, efficiency curve, overhaul frequency, etc. For renewables, the sun incidence is obtained through the internet inserting the coordinates. The wind speed and direction will be obtained through specific software. The result for the first stage analysis will be the optimal system size for the Distributed Generation System, produced energy of the system and also the avoided cost, which is the revenue of the investment.

The second stage is Sirius Power. In this program, a financial analysis will be performed considering the installed technology cost, maintenance cost, and fuel cost, if applicable. The revenue of the project is represented by the avoided cost. Another important input is the government incentives, usually represented by rebates of installed costs and also a reward considering the energy generated in the first five years. The depreciation of the system is also calculated for tax purposes, if the entity is taxable. As a result, Sirius Power will produce the profitability of the project, including the Net Present Value, Internal Rate of Return, the Leveled Cost of Energy and the Pay Back period. The figure below shows the diagram of the final solution approach:

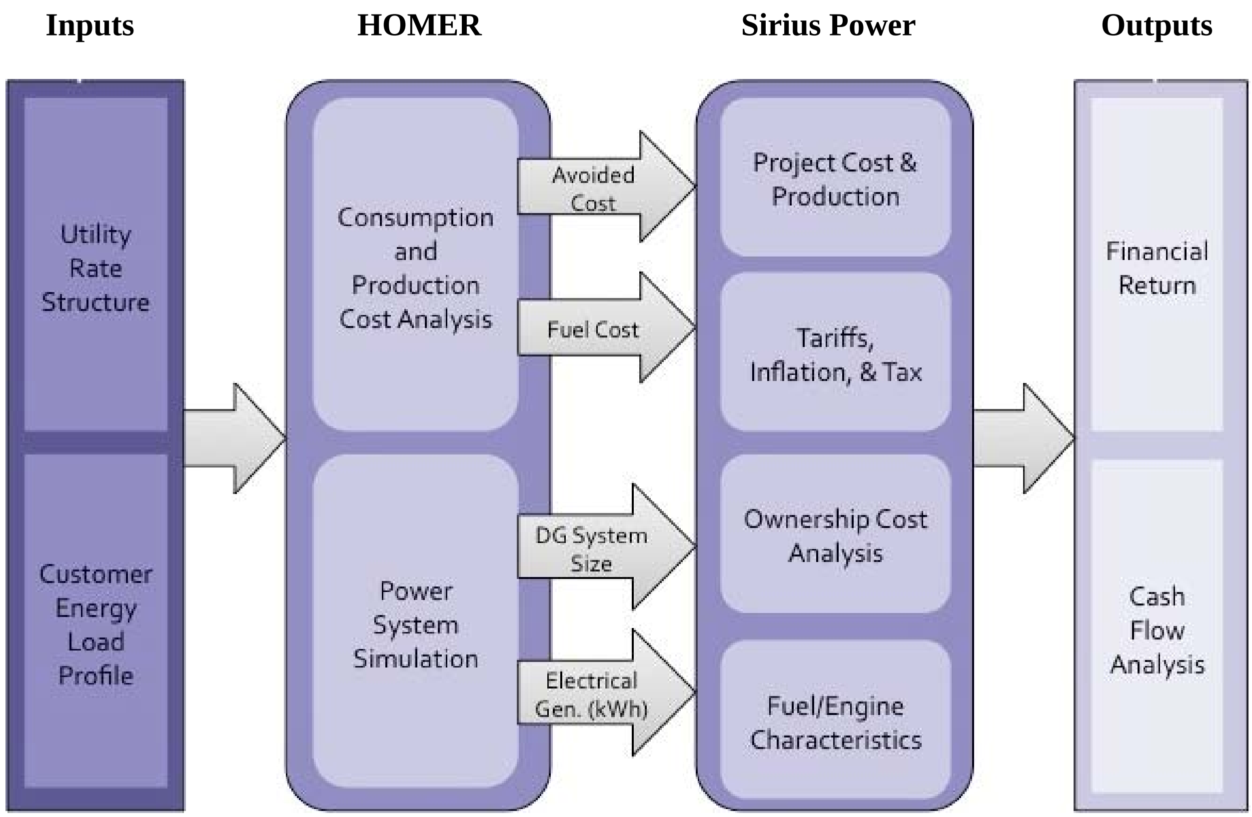


Figure 1 - Final Solution Diagram

V. Implementation of the Top Design

In order for this program to be developed, the following tasks must have been completed:

	Tasks for Implementation
1	Gather customer daily profiles for each utility
2	Research utility rate structures
3	Research federal/state incentive programs
4	Gather DG technology information
5	Perform simulations in HOMER for each customer/utility
6	Develop Sirius Power program using C++
7	Establish interface between HOMER and Sirius Power

Residential, commercial, and industrial customers were analyzed for two electric utilities: Pacific Gas & Electric and Xcel Energy.

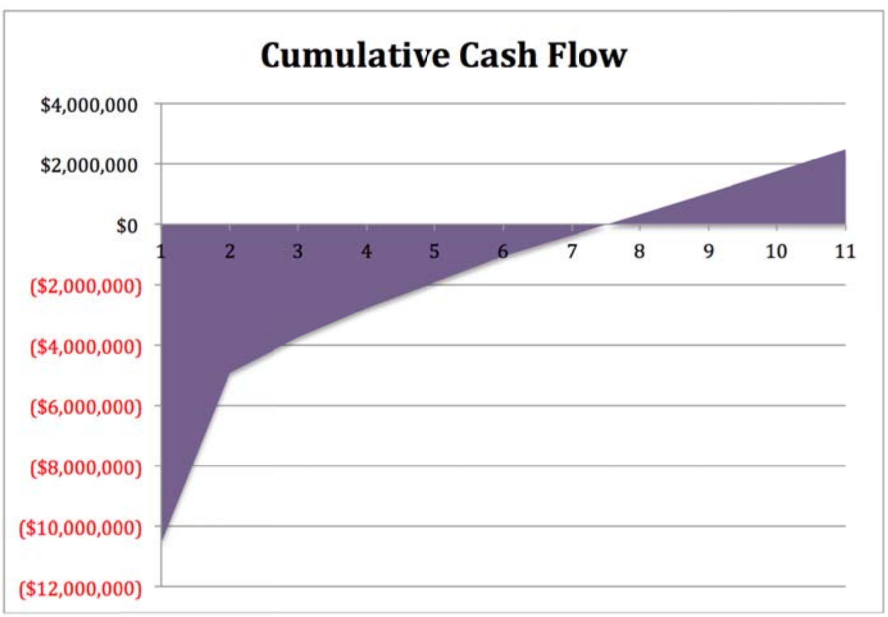
VI. Performance Analysis and Evaluation of the Project

A. Tables/Graphs

Below are the financial returns of an industrial customer generated by Sirius Power. The customer was evaluated against the two utilities, Pacific Gas & Electric and Xcel Energy. The results were first displayed in Sirius Power and then exported to an excel spreadsheet in order to plot the cumulative cash flow.

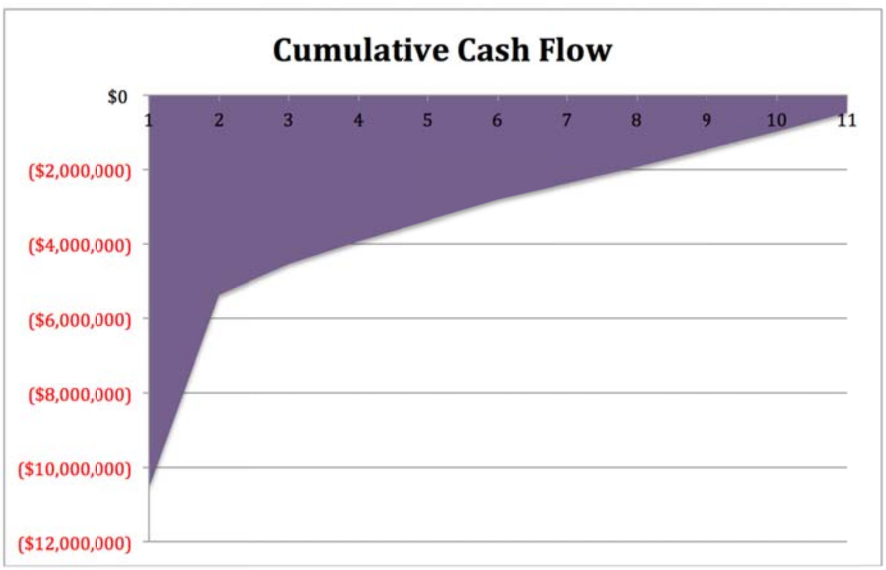
PG&E Industrial Customer Financial Return

System Price:			$6,764,000								
Year:	0	1	2	3	4	5	6	7	8	9	10
Production Cost:		$5,326,080	$5,299,449	$5,272,819	$5,246,189	$5,219,558	$5,192,928	$5,166,297	$5,139,667	$5,113,037	$5,086,406
Avoided Cost:		$448,452	$468,521	$489,475	$511,353	$534,195	$558,043	$582,940	$608,932	$636,066	$664,391
Incentives (kWh):		$170,434	$169,582	$168,730	$167,878	$167,025	$166,173	$165,321	$164,469	$163,617	$162,765
Revenue/Avoided Costs:		$618,887	$638,103	$658,205	$679,231	$701,221	$724,216	$748,262	$773,401	$799,683	$827,156
O&M:		$57,000	$58,425	$59,885	$61,382	$62,917	$64,490	$66,102	$67,755	$69,448	$71,185
Insurance:		$52,820	$54,140	$55,494	$56,881	$58,303	$59,760	$61,254	$62,786	$64,356	$65,964
Expenses:		$109,820	$112,565	$115,379	$118,264	$121,220	$124,251	$127,357	$130,541	$133,804	$137,150
Cumulative Cash Flow	($10,564,000)	($4,920,829)	($3,747,189)	($2,776,607)	($1,920,573)	($1,057,509)	($367,510)	$331,423	$1,040,308	$1,760,207	$2,492,229
Net Present Value:	($420,735)										
Levelized Cost ($/kWh):	$0.09										
Breakeven/Payback Year:	7										
IRR:	5.17%										



Xcel Industrial Customer Financial Return

System Price:			$6,764,000								
Year:	0	1	2	3	4	5	6	7	8	9	10
Production Cost:		$5,326,080	$5,299,449	$5,272,819	$5,246,189	$5,219,558	$5,192,928	$5,166,297	$5,139,667	$5,113,037	$5,086,406
Avoided Cost:		$395,192	$412,876	$431,342	$450,622	$470,751	$491,766	$513,707	$536,612	$560,523	$585,484
Incentives (kWh):		$79,891	$79,491	$79,092	$78,692	$78,293	$77,893	$77,494	$77,095	$76,695	$76,296
Revenue/Avoided Costs:		$475,083	$492,368	$510,434	$529,314	$549,044	$569,660	$591,201	$613,707	$637,219	$661,780
O&M:		$38,000	$38,950	$39,923	$40,921	$41,944	$42,993	$44,068	$45,170	$46,299	$47,456
Insurance:		$84,512	$86,624	$88,790	$91,010	$93,285	$95,617	$98,008	$100,458	$102,969	$105,543
Expenses:		$122,512	$125,574	$128,714	$131,932	$135,230	$138,611	$142,076	$145,628	$149,268	$153,000
Cumulative Cash Flow	($10,564,000)	($5,380,833)	($4,542,621)	($3,922,048)	($3,375,069)	($2,811,658)	($2,380,608)	($1,931,482)	($1,463,404)	($975,453)	($466,674)
Net Present Value:	($2,501,671)										
Levelized Cost ($/kWh):	$0.09										
Breakeven/Payback Year:	11										
IRR:	1%										



B. Evaluation Against the Design Requirements

Sirius Power delivered the desired results accurately as, unlike HOMER, it takes into account government incentives. However, the Sirius Power-HOMER interface could undergo further development for improved user friendliness.

VII. Conclusion and Recommendations

To determine the financial return of the most economically efficient distributed generation solution for industrial, commercial, and residential customers, the program Sirius Power was proposed. This program was able to take customer information, utility rate structures, technology specifications, and incentives and use these inputs to determine the financial return of the most economical method for distributed generation that will meet the customer's electricity needs. There was no established budget for the project, but consultations with Howard University professors and students were necessary for completion of the program. Sirius power successfully takes customer and utility data and accurately outputs the financial return due to its inclusion of government incentives. However, further development could be undergone to improve the Sirius Power-HOMER interface because, for now, users are required to manually input the results from HOMER into Sirius Power. It is recommended that the program be modified and expanded to include more electric utilities, government incentives, and distribute generation technology. This would allow the program to become more versatile and useful to a wider range of customers.

IX. References

[1] S. Meliopoulos, J. Momoh, and R. Saint, "Centralized and Distributed Generated Power Systems – A Comparison Approach." PSERC. Jun. 2012.

[2] J.B. Ekanayake, N. Jenkins, and G. Strbac, "Introduction," in *Distributed Generation*, London, UK: IET, 2010, ch. 1, pp. 1-4.

[3] Introduction to Distributed Generation [Online]. Available: http://www.dg.history.vt.edu/ch1/introduction.html

[4] Welcome to SAM [Online]. Available: https://sam.nrel.gov

[5] Energy Modeling Software for Hybrid Renewable Energy Systems [Online]. Available: http://homerenergy.com

X. Appendix

A. Final Design Requirement

System	Description
Functionality	◆ Perform economic calculations and output user's avoided cost and yearly cash flow
User Interface	◆ Allow user to specific electric utility, system technology, and system size. ◆ Allow user to export cash flow data to spreadsheet.
Capabilities	◆ Perform calculations based on built-in database of utility rate structures and government taxes.
Others	◆ **Accessible to any operation system.** ◆ **Ease of use (Can be used on personal computers).**

B. Source Code Listing

The following is some of the code included in the development of Sirius Power:

```
//Yearly Financial Calculations
float yearly_production = (1-0.005*(i-1))*year_prod(system_size, cap_factor);
string yearly_prod = commify(yearly_production);

float year_avoid_solar = tariff_avoided*pow((1+inflation),(i-1))*yearly_production;
string yearly_avoid_solar = commify(year_avoid_solar);

float year_avoid_other = (tariff_avoided*pow((1+inflation),(i-1))*yearly_production+natural_gas_avoid*pow((1+inflation),(i-1)));
string yearly_avoid_other = commify(year_avoid_other);

float year_incent = incentive*yearly_production;
string yearly_incent = commify(year_incent);

float year_OM = OM_first_yr*pow((1+esc_rate),(i-1));
float year_insurance = insurance_first_yr*pow((1+esc_rate),(i-1));
string yearly_OM = commify(year_OM);
string yearly_insurance = commify(year_insurance);



float PGE_natgas_avoid(float hour_capacity, string DG_tech) {

    float exhaust_gas;
    if (DG_tech == "Fuel") {
        exhaust_gas = 2*808000;
    }
    else {
        exhaust_gas = 3*1350000;
    }
    float PGE_natgas = 0.85;
    float recovery_fac = 0.5;
    float natgas_avoid = PGE_natgas*exhaust_gas/100000*hour_capacity*recovery_fac;
    return natgas_avoid;
}

float hour_cap(float cap_factor) {

    float hr_cap = 8760*cap_factor;
    return hr_cap;
}

float year_prod(float system_size, float cap_factor) {

    float product_cost = system_size*cap_factor*8760;
    return product_cost;
}

float dem_avoid (float system_size, float total_cost, float avoided_cost) {

    float dem_avoid_yr = 12*system_size*avoided_cost;
    return dem_avoid_yr;
}

float cash_inflow (float year_rev_avoid, float fed_tax_shield, float state_tax_shield, float state_rebate, float invest_tax_credit) {

    float cash_inflow = year_rev_avoid+fed_tax_shield+state_tax_shield+state_rebate+invest_tax_credit;
    return cash_inflow;
}

float solar_cash_outflow (float year_expenses, float total_cost) {

    float cash_outflow = -year_expenses+total_cost;
    return cash_outflow;
}
```

PHATHOM A. DONALD

Present Address:
6515 Belcrest Road, Apt 1311C
Hyattsville, MD 20782
(213) 595-1994

Permanent Address:
2016 South Rimpau Blvd
Los Angeles, CA 90016
(323) 933-3069

phathom.donald@gmail.com

EDUCATION

Bachelor of Science in Electrical Engineering **May 2014**
Howard University, Washington, DC
- Honors: Howard University Legacy Scholarship, IEEE-Eta Kappa Nu Nominee
- Coursework: Linear Control Systems/Lab, Power Communications & Control, Power Systems Analysis, Communications Theory, Electronics/Lab, Digital Systems Design/Lab, Computer Science
- **Major GPA: 3.58/4.0**

TECHNICAL SKILLS

- Hardware: Arduino, Altera FPGA, Probe Station, Semiconductor Parameter Analyzer, Oscilloscope, Multimeter, Function Generator, and Soldering Iron
- Software/Applications: MATLAB, Altera Quartus II, Microstation, ProjectWise, WMIS, NEPLAN, PSAT, PSpice, Visual Studio, Microsoft Office, and Xcode
- Programming: C++, VHDL, and Java
- Platforms: Microsoft Windows, and Mac OSX

EXPERIENCE

Student Engineer **May 2013 - August 2013**
Los Angeles Department of Water and Power, Los Angeles, CA
- Prepared construction drawings, sketches, and diagrams related to the planning of electrical service for residential, and commercial customers
- Consulted with Department personnel to determine methods for providing electrical service for customers
- Produced engineering calculations necessary for generating material lists, cost estimates regarding electrical apparatus such as transformers and electrical cables
- Efficiently assisted in research for planning future sources of power

Volunteer Intern **January 2013 - May 2013**
Center for Energy Systems and Control, Howard University, Washington, DC
- Effectively aided in the managerial responsibilities of the center including proposal writing, organizing a summer outreach program, and preparing project presentations to the center collaborators such as ICPSOP, PSERC, and FAA

Research Intern **May 2012 - August 2012**
Rensselaer Polytechnic Institute Smart Lighting ERC, Troy, NY
- Conducted research on the physics, structure, and characterization of MOSFETs through ample reading and device testing
- Employed silicon wafers, a probe station, and a semiconductor parameter analyzer to plot and compare the transfer curves and outputs of various MOS transistors
- Instructed high school teachers on how to solder devices onto printed circuit boards and use Mobile Studio so they could incorporate electrical engineering in their courses
- Attended Leadership courses on topics including research misconduct and managing a team

DESIGN PROJECTS

Howard University Rocket Initiative, RockSat-C 2014 **January 2014 - present**
- Collaborate with engineering students to plan, design, and construct a rocket payload that will acquire atmospheric samples to verify the presence of organisms
- Program the interface between Arduino Uno board and solenoid valves for collecting samples
- Develop the electrical design and power supply system configuration

Sirius Power, Senior Design Project **August 2013 - April 2014**
- Built a computer program that takes customer and utility data and outputs the financial return of the most cost-effective method of distributed generation that meets the customer's electrical needs
- Collaborated with computer science students and an international electrical engineering student to research distributed generation technology and apply engineering economics to the program development