Technology Selection and Unit Sizing for a Combined Heat and Power Microgrid: Comparison of WebOpt and HOMER Application Programs

A.J. Litchy, *Student Member*, *IEEE*, C. Young, *Student Member*, *IEEE*,
S.A. Pourmousavi, *Student Member*, *IEEE*, and M.H. Nehrir, *Fellow*, *IEEE*
Electrical Engineering Department
Montana State University
Bozeman, USA

***Abstract*— The purpose of this paper is to design an optimal CHP islanded microgrid, through technology selection and unit sizing software, to be used for further research on real-time energy management. Two software packages, HOMER® and WebOpt®, originally developed at the National Renewable Energy Laboratory (NREL) and Lawrence Berkley Laboratory (LBL), respectively, are utilized. Using these programs, different cases are created and compared to justify the selected technologies and their respective prices. The final microgrid design contains renewable and alternative energy generation, hydrogen as an energy carrier, and electric storage.**

I. INTRODUCTION

RENEWABLE and alternative energy distributed generation (DG) sources, energy storage, and combined heat and power (CHP) are very promising technologies which can help reduce undesired emissions and fossil fuel dependence, and improve energy efficiency and reliability. While DG technologies are able to operate on their own, higher efficiency can be obtained by incorporating energy storage and CHP (when possible) as a hybrid system. The waste heat of DG sources, such as fuel cells and diesel engines, can be used for water heating, space heating, or cooling through the use of absorption chillers, to increase their efficiency [1]. As a result, the overall fuel consumption and emissions are reduced in such hybrid systems.

The intermittent nature of renewable energy generation sources, such as photovoltaic (PV) and wind power generation, has effects on the stability of the grid and availability of power [2], [3]. One way to increase the benefits of those technologies and mitigate their negative impacts is to use access and capacity-oriented energy storage. Access-oriented energy storage uses fast-acting energy storage technologies, such as a supercapacitor or flywheel, to respond quickly to the rapid changes in generation and load. Capacity-oriented energy storage utilizes technologies, such as hydrogen storage, to store excess generated energy to be used at a later time of need [4].

This work was in part supported by the DOE Award DE-FG02-11ER46817 and by Montana State University.

Aric J. Litchy (email: aric.litchy@msu.montana.edu), Colin Young (email: colin.young@msu.montan.edu), S.A. Pourmousavi (email: s.pourmousavikani@msu.montana.edu), and M.H. Nehrir (email: hnehrir@ece.montana.edu) are with the Electrical and Computer Engineering Department, Montana State University, Bozeman, 59717 USA.

One way of operating the hybrid system is under the microgrid concept. The Microgrid Exchange Group defines a microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid” [5]. It can operate in either grid-connected or islanded mode and range in sizes from a single household to a large neighborhood. It can also be designed in different types of configurations such as AC-coupled, DC-coupled, or a hybrid of the two [2]. A sample AC-coupled microgrid architecture including CHP is shown in Fig. 1. The type, size, and operation schedule of the technologies in a microgrid depend on several factors; mainly the cost and lifetime of the different available technologies, type and size of loads, typical weather conditions, and the type of optimization objective function.

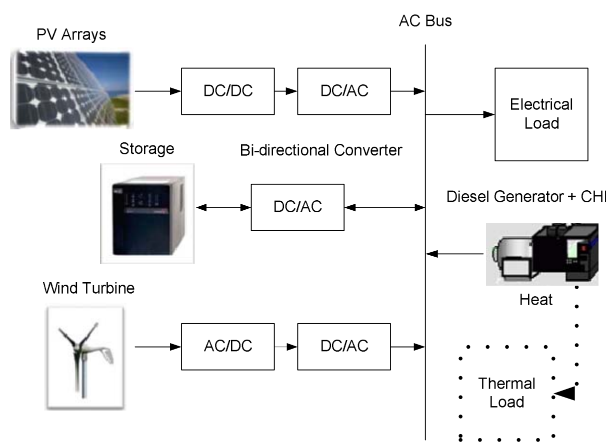

Fig. 1. AC-coupled microgrid with DG sources, storage, and CHP.

This paper shows the use of two different publicly available software packages, The Hybrid Optimization Model for Electric Renewables (HOMER®) [6] and Distributed Energy Resources Web Optimization Service (WebOpt®) [7], [8] developed by National Renewable Energy Laboratory (NREL) and Lawrence Berkley National Laboratory (LBL), respectively. They are used to select and size the proper technologies for a microgrid with practical thermal and electrical loads. The purpose of designing this microgrid is to use it for real-time energy management in future research. Through the design process, it is also desired to show the operation and benefits of each design tool. Real load data from a medium-sized college in San Francisco, CA, which is available through the WebOpt software, is used. This load is included in the California Commercial End-Use Survey (CEUS) [9].

Three different cases are used to justify the final design of the CHP microgrid. Since the two programs have different way of entering inputs and settings, a base case (Case A) was designed to show that these settings were implemented in a similar manner. In this case, the same types of technologies are chosen to be available by both programs. Two other cases are studied; one involves microgrid design with WebOpt alone (Case B) and one with HOMER alone (Case C). These two cases focus on the advantage of technologies that are not available in the other program. Also, within each of the two cases (B, C) two simulations are carried out, one with the original settings and price data and the other with adjusted settings and price data to justify the changes necessary to incorporate renewable and alternative technologies.

The rest of the paper is organized as followed. Section II briefly describes both of the programs WebOpt and HOMER. In section III, the simulated cases are described in detail along with the results of each one. Section IV presents a discussion on the results and experience of using the two software packages and the final microgrid design is given. Finally, conclusions and future research are reported in section V.

II. Brief Description of WebOpt and HOMER

A. WebOpt

The Distributed Energy Resources Web Optimization Service (WebOpt) is an optimization tool to minimize the cost or emissions for meeting electrical and thermal load demand of a microgrid based on a one-hour time step [7]. WebOpt is based on the Distributed Energy Resources Customer Adoption Model (DER-CAM), a mixed integer linear programing (MILP) tool, implemented on the General Algebraic Modeling System (GAMS) [10]. It is the free non-commercial web-accessible version and nothing needs to be installed on the local system. It is available from LBL. However, it does not contain all the features that the more advanced version, DER-CAM has, e.g. electric vehicle simulation option, stochastic programming, or 5-min time-step optimization, etc. nor does it show the mathematical DER-CAM model [11]. This paper just focuses on the WebOpt interface and more information on the full DER-CAM version can be found in [7].

WebOpt helps to find the best combination and capacity of the different DER technologies available to meet the desired goals of the user. Constraints involved in the optimization process require that 100% of each end-use load is met (unless the demand response option is utilized) and the thermodynamics of the system are obeyed. It gives a schedule of operation for the different technologies in the results, as well.

WebOpt (and DER-CAM) separates its technologies into two categories, continuous and discrete. Some available technologies are PV, fuel cell + heat exchanger (FC-HX), absorption chillers, batteries, internal combustion engine (ICE), etc. The discrete technologies can only be purchased in increments of the set capacity value, e.g. if the fuel cell capacity is set at 100 kW, then the available capacity values would be 100, 200, 300 kW, etc. The continuous technologies' capacities can be any size, e.g. 110.5 kW.

Different settings selections and data input are implemented through a series of windows in the main interface of WebOpt. The first window labeled, overview/optimization settings, determines which optimization objective will be used, either cost or CO_2 minimization, as well as the investment of DER to be considered in the simulation. The other windows are used to input the load data, utility rates, technology prices and characteristics, demand response parameters, hourly solar radiation data, and CO_2 emissions from the conventional generators on the grid side.

Once the simulation has completed, the results are shown in the last window of the WebOpt program. The results contain optimal technology and capacity selection, annualized cost data, total fuel consumption, utility electricity and utility natural gas consumption, and CO_2 emissions data. The results also show area plots of how all the different load profiles are met for the weekdays, weekends, and peak profiles for each month.

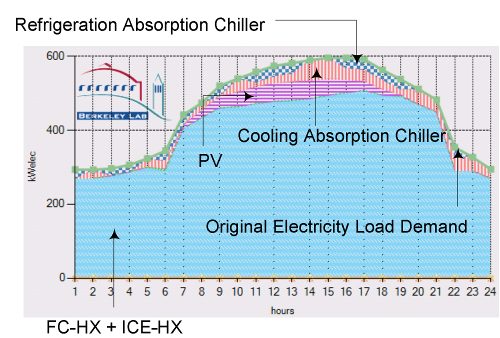

Fig. 2. WebOpt area plot example of a typical electrical load demand in summer, met by the different generation sources in a 24 hour period.

Fig. 2 is an example of the WebOpt results area plot, where a demand profile and the operation period of the different available technologies are shown. This example shows the addition of the absorption chillers offsets some of the original electrical load demand by providing the necessary cooling through the generated waste heat.

B. HOMER

The Hybrid Optimization Model for Electric Renewables (HOMER) software was originally developed at the National Renewable Energy Laboratory (NREL) and now a commercial version (which has been made available to the authors) has been developed by HOMER Energy, LCC. The results in this paper are solely from the free public version of HOMER, so that a fair comparison is made between this version and WebOpt.

The HOMER energy modelling software is a tool for designing and analyzing hybrid power systems, which can contain a variety of technologies. For either grid-tied or islanded-mode, HOMER helps determine how intermittent resources, such as wind and solar, can be optimally integrated into microgrids. The economic feasibility of a hybrid energy system and optimization of the system design are the ultimate goals in HOMER. It will help to mitigate the financial risk of a hybrid power system at the design process [6].

The model requires inputs such as technology options, component costs, and resource availability. The inputs are used to simulate different system configurations, and create a list of feasible configurations sorted by net present cost (NPC).

HOMER is an hourly simulation model; it models system components, available energy resources, and loads on an hourly basis for one year. Energy flows and costs are assumed to be constant over any given hour. The user can enter in hourly data but HOMER can also synthesize hourly load resource data from monthly averages as well.

Technologies available in HOMER are PV, wind turbine generator, batteries, hydrogen storage, and generic generators. The generator technology could be an ICE, FC, microturbine, gas turbine, or another type of generator depending on its generator settings, i.e. the fuel source, efficiency, lifetime, etc. [6]. All of these technologies can be connected through a DC bus with a DC/AC converter or directly to an AC bus. Also, the considered capacities of the technologies are selected by the user. At first, the user enters a discrete range of technology capacities. After HOMER simulates all of the possible system configurations, it displays a list of feasible systems, sorted by lifecycle cost. At the top of the list is the least cost system [12]. Using a simple direct search method the user can find the near optimal scenario by narrowing the previously considered discrete range of capacities based on the previous simulation results.

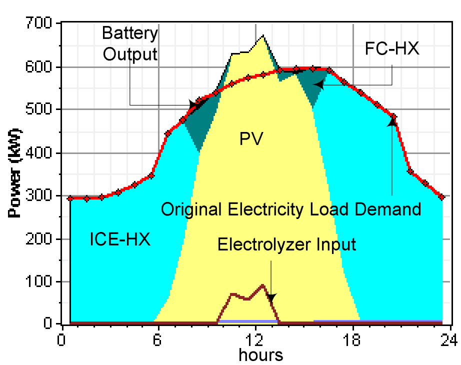

Fig. 3. Example of an area plot of the electrical load demand being met by the different generation sources over a 24 hour period from HOMER.

HOMER produces summary graphs and tables for each possible configuration displaying the system's cost summary, technology hourly output power, fuel consumption, etc. It also has the ability to export the raw hourly data so the results can be analyzed by the user as needed. Fig. 3 is a sample area plot produced by the user in HOMER, where several technologies including ICE-HX, storage battery, PV, and FC-HX are used to supply the demand. The operation period of the different technologies are shown in the figure. When the PV power is greater than the load demand, the electrolyzer is run to produce hydrogen which is stored for later use by the FC.

III. Simulation Setup and Results

Different simulation cases were setup to compare the performance and show the unique qualities between the two software packages for designing a microgrid. Fig. 4 shows the load demand profile for a typical summer day of a medium-sized college in San Francisco, CA, which has been used in the two programs for technology selection.

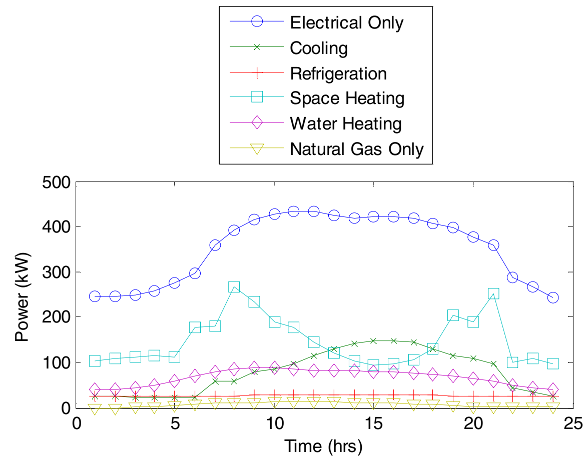

Fig. 4. Sample load demand profile for a typical summer day of a medium-sized college in San Francisco, CA.

The electrical only load consists of lighting, appliance, and other demands that can only be met by electricity. The cooling and refrigeration loads can be met by either electricity or generated waste heat through the use of absorption chillers. Space and hot water heating are met by either generated waste heat or natural gas. The natural gas only load is mainly demand from cooking. For WebOpt, each of these loads are input separately, but in HOMER the cooling and refrigeration loads were added to the electricity load since they can only be met through electricity and not generated waste heat. The space and water heating loads were combined along with the natural gas only load to create one thermal load in the system as well. The selected technologies, their capital and maintenance costs, lifetime, and efficiencies are given for each case. The results for each case contain the capacity size of each technology, total annualized cost, annual consumption and cost of fuel.

Case A: Base Case

This case was designed to show the inputs for the loads, prices, and other settings were implemented similarly for both programs. PV, battery, FC-HX, and ICE-HX are the selected technologies to be considered since the technologies needed to be available by both programs. Table V shows their capital cost, O&M cost, efficiency, and lifetime inputs used for both application programs [13]-[15].

Two issues with WebOpt, no islanded mode of operation and the consideration of all the natural gas-based DER technologies at once, needed to be resolved. This was done by setting the utility electricity rates and the unwanted DER technologies' prices to the highest possible input value to deter the program from purchasing electricity from the utility and selecting the undesirable technologies. Since WebOpt only considers natural gas as a fuel source and its unit price is set in \$/kWh, HOMER is also set to only consider natural gas as the fuel source and the unit price is converted from \$/kWh to \$/m^3 to be applicable in HOMER. The natural gas rates used are 0.04 \$/kWh and 0.395 \$/m^3, for WebOpt and HOMER, respectively. This natural gas rate is grabbed from the WebOpt software. The project lifetime is set to 25 years.

TABLE V
CASE A: WEBOPT & HOMER TECHNOLOGY INPUT DESCRIPTIONS

Tech. Selection	Capital Cost (\$/kW, \$/kWh for Battery)	Annual O&M Cost (\$/kW, \$/kWh for Battery, FC, ICE)	[d]Elec. Eff. (%)/ CHP Eff. (%)/ Recov. Heat (kW/kW)	[e]Lifetime (Years/ Hours of Use)
PV[a]	5000	18.00		20
Battery[b]	139	9.26	85	6
FC-HX[c]	4500	0.03	40/70/1.0	10/160,000
ICE-HX[c]	1200	0.01	40/75/1.25	20/40,000

[a]PV data was obtained from NREL [13], [b]Battery data was obtained from DOE [14], [c]FC-HX and ICE-HX data was obtained from [15]. [d]In HOMER, CHP efficiency is a percent and in WebOpt it is recoverable heat in kW per electrical output in kW. [e]Lifetime in WebOpt is in years for FC-HX and ICE-HX, whereas in HOMER it is in hours of use.

As noticed from Table VI, similar results are obtained from both programs in case A. The results show that the ICE-HX is the main technology selected to meet the load demands for both WebOpt and HOMER, where the proposed capacities are 650 kW and 625 kW, respectively. It can be noticed from the results that 0.1 kW of PV generation is recommended by WebOpt, while it is zero in the case of HOMER. The 0.1 kW difference is negligible compared to the total generation capacity of the hybrid system. Since there is a small investment in PV, this could be one reason why there is a small discrepancy in invested battery capacity between the two programs as well.

TABLE VI
CASE A: WEBOPT & HOMER RESULTS

	WebOpt	HOMER
Tech. Selection	Size (kW, kWh for Battery)	
PV	0.1	0.0
Battery	19.3	8.64
FC- HX	0.0	0.0
ICE-HX	650	625
Total Ann. Cost (\$/yr)	484,664	518,578
Total Fuel Con. (kWh/yr)	9,464,385	9,832,548
Fuel Cost (\$/yr)	378,575	393,302

Also, similar total annualized cost, total fuel consumption, and total fuel cost are shown. The results between the two programs do not show any glaring differences, justifying the inputs and settings were implemented in a similar manner.

Case B: WebOpt Only

This case only involved WebOpt as the program for the microgrid design. The same settings are used as in Case A, plus the addition of the cooling and refrigeration absorption chillers. The absorption chillers improve the efficiency of the system through use of waste heat to serve the cooling and refrigeration loads, instead of increasing electrical generation with the use of more fuel. Two scenarios are performed, one with normal prices as in Case A, and another with adjusted prices and settings so that the optimal design included all the technologies considered. Table VII shows the setting details of both scenarios. Results of the technologies and capacities selected by WebOpt for both scenarios are given in Table VIII.

TABLE VII
CASE B: WEBOPT TECHNOLOGY INPUT DESCRIPTIONS

	Tech. Selection	Capital Cost (\$/kW, \$/kWh for Battery)	Annual O&M Cost (\$/kW, \$/kWh for Battery, FC, ICE)	Elec. Eff. (%)/ Recov. Heat (kW/ kW)	Lifetime (Years)
Scenario 1: Unadjusted Prices	PV	5000	18.0		20
	Battery	139	9.26	85	6
	FC-HX	4500	0.03	40/1.0	10
	Abs. Chil. Refrig.[f]	831	0.00		20
	Abs. Chil. Cooling[f]	831	0.00		20
	ICE-HX	1200	0.01	40/1.25	20
Scenario 2: Adjusted Prices	PV	2750	18.0		20
	Battery	75	2.40	85	10
	FC-HX	1200	0.02	40/1.0	10
	Abs. Chil. Refrig.	831	0.00		20
	Abs. Chil. Cooling	831	0.00		20
	ICE-HX	1200	0.02	35/1.25	20

[f]Abosrption chiller data was obtained from SMUD [16].

Case B (the WebOpt only simulations) shows major changes to the price of technologies are needed in order to incorporate the desired technologies. For Scenario 1, as in Case A, the major generation source is the ICE-HX which is rated at 580 kW. However, compared to WebOpt in Case A, the capacity is reduced by 70 kW because of the added absorption chillers which is offsetting parts of the electrical load used for refrigeration and cooling. The absorption chillers are rated at 27.2 kW (for refrigeration) and 82.2 kW (for cooling). None of the other technologies were selected; which is due to the high cost of PV and FC-HX.

In order to have the FC-HX and PV as competitive technologies, their prices were reduced in Scenario 2. The price of the FC-HX is reduced to that of the ICE-HX, along with a decrease in efficiency for the ICE-HX. Also, the PV and battery capital costs are reduced to 55% and 54%, respectively, of their original prices. The battery O&M cost was also reduced, along with an increase in its lifetime. With the new prices and settings, WebOpt selected a good combination of the FC-HX and ICE-HX, 280 kW and 300 kW, respectively. Also, the recommended capacities of the PV and batteries are practical at 39.6 kW and 41.7 kWh, respectively.

TABLE VIII
CASE B: WEBOPT ONLY RESULTS

	Scenario 1: Unadjusted Prices	Scenario 2: Adjusted Prices
Technologies Considered	Size (kW, kWh for Battery)	
PV	0.0	39.6
Battery	0.0	41.7
FC-HX	0.0	280
Absorption Chiller Ref.	27.2	27.2
Absorption Chiller Cooling	82.2	68.0
ICE-HX	580	300
Util. Elec. Con. (kWh/a)[g]	145	109
Total Annualized Cost ($/yr)	475,061	553,170
Total Fuel Con. (kWh/yr)	8,930,624	9,453,594
Fuel Cost ($/yr)	357,225	378,144

[g]Since WebOpt cannot limit the microgrid to islanded mode there can still be a little amount of utility electricity consumption even though the rates are maxed out, due to the constraint of the load being met 100%.

These adjustments, which resulted in the selection of additional technologies, had an effect on the cooling absorption chiller capacity, reducing it to 83% of its recommended capacity in Scenario 1. The refrigeration absorption chiller capacity remained the same. However, even though the results from Scenario 2 present a desirable combination of different technologies, it is achieved with significant price reduction of renewable technologies.

Case C: HOMER Only

Case C only deals with HOMER as the tool for the microgrid design. As in Case B, two scenarios are carried out to show the required modifications in prices and settings to create a microgrid that included all of the desired technologies. In Scenario 3 the same settings are used as in Case A, with the added technologies, an electrolyzer and a hydrogen tank, to incorporate another option for energy storage.

TABLE IX
CASE C: HOMER TECHNOLOGY INPUT DESCRIPTIONS

	Tech Selection	Capital Cost ($/kW, $/kWh for Battery, $/kg for H_2 Tank)	Annual O&M Cost ($/kW or $/kWh for Battery, FC, ICE)	Elec. Eff./ CHP Eff. (%)	Lifetime (Years, Hours of Use)
Scenario 3: Unadjusted Settings	PV	5000	18.0		20
	Battery	139	9.26	85	6
	FC-HX	4500	0.03	40/70	40,000
	ICE-HX	1200	0.01	35/75	160,000
	Elect.[h]	1000	0.00	80	15
	H_2 Tank[i]	650	0.00		25
Scenario 4: Adjusted Settings	PV	5000	18.0		20
	Battery	278	9.26	85	6
	FC-HX	4500	0.03	40/70	40,000
	ICE-HX	1200	0.01	35/75	160,000
	Elect.	1000	0.00	80	15
	H_2 Tank	650	0.00		25

The electrolyzer data is from [17], [i]and the hydrogen tank data from [18].

Scenario 4 includes a minimum renewable fraction setting of 20% so that the technology price data does not need to be changed drastically, as it was in Case B with WebOpt. This setting simply means that the final design will include at least 20% renewable generation regardless of the renewable technology price. Table IX shows the settings of the scenarios.

In Scenario 4, the battery price is the only technology price adjusted and it is 100% more than the original price. This is done to limit the amount of capacity purchased so that hydrogen storage was invested in as well. Table X displays the results of both scenarios.

Case C (where only HOMER was used) shows, as in Case B, that changes needed to be made in order to create a microgrid that incorporates the desired renewable technologies. In Scenario 3, with just the addition of the desired technologies, the exact same results are obtained as in the HOMER simulation in Case A (Tables X, VI). The results of Scenario 4 show a significant increase in the PV capacity, from zero to 700 kW. The proposed hydrogen storage system in the structure includes a 50 kg H2 tank, 100 kW electrolyzer, and 100 kW FC-HX. The battery capacity also increased even though the price was increased by 100%; this is because of the large investment in PV. Including the renewable fraction constraint in the simulation limited the required price changes, and as a result of the major investment in the renewable technologies, the cost of the whole system is increased in Scenario 4 compared to all the other scenarios.

TABLE X
CASE C: HOMER ONLY RESULTS

	Scenario 3: Unadjusted Settings	Scenario 4: Adjusted Settings
Tech Selection	Size (kW, kWh for Battery, kg for H_2 Tank)	
PV	0.0	700
Battery	8.64	43.2
FC-HX	0.0	100
ICE-HX	625	750
Electrolyzer	0.0	100
Hydrogen Tank	0.0	50
Total Annualized Cost ($/yr)	518,578	800,658
Total Fuel Con. (kWh/yr)	9,832,548	7,521,647
Fuel Cost ($/yr)	393,302	300,866

IV. DISCUSSION

Through the comparison of the results obtained from the two software packages, it is noted that WebOpt is found valuable for its use with CHP strategies and HOMER is valuable for its additional setting options, like the minimum renewable fraction and islanded operation. WebOpt's ability to enter in electrical, heating, and cooling loads separately and the included availability of absorption chillers enhances the use of CHP applications. The results show that adding the consideration of the absorption chiller technologies alone decreases the total annualized cost and fuel consumption of the system. WebOpt is also able to find the true optimal technology selection and size for the system's settings, without relying upon the user. Unfortunately, at the present time major changes in the pricing of the technology is required in order to increase the amount of renewable generation. Also for WebOpt, utility rates and some technology costs need to be maxed in order to deter the program from considering them.

HOMER's inclusion of a minimum renewable energy fraction setting allows for a larger investment in renewable technologies without drastically decreasing the price of those technologies. HOMER has the ability to consider an islanded microgrid and include CHP strategies, but for heating loads only. It can also consider each technology individually, whereas WebOpt does not have this feature, but it is included in its upgraded version, DER-CAM. HOMER, while providing the least cost system out of all the different considered configurations, it is a simulation tool which relies upon the user to find the near-optimal system configuration. Since it only takes specific capacities (not a continuous capacity range) entered by the user, there could be a more optimal capacity that is not being considered.

V. Conclusions and Future Work

Technologies were optimally selected and sized for a medium-sized college in San Francisco containing electrical and thermal loads. Two software packages (WebOpt and HOMER) developed by the US national laboratories LBL and NREL, respectively, were used to perform the optimal sizing and technology selection. Three cases were used to justify the adjustments made to create a microgrid that incorporates different renewable/alternative generation sources including energy storage and CHP. The final microgrid structure, Scenario 4 with optimization through HOMER, contained PV, FC-HX, ICE-HX, batteries, and hydrogen storage technologies. A comparison of the operation and benefits of WebOpt and HOMER was also accomplished through the design process.

The final microgrid design will be used to study real-time energy management, which is a multi-objective optimization problem. Intelligent control along with heuristic optimization techniques will be used to solve the optimization problem. Optimization objectives will include minimization of operation costs and emissions.

Acknowledgement

The authors acknowledge the use of the application programs, WebOpt and HOMER, originally developed by LBL and NREL, respectively. They also acknowledge HOMER Energy, LLC for providing them a commercial version of the HOMER software, as well as the valuable comments of Dr. Michael Stadler of LBL on the paper.

References

[1] C. M. Colson and M. H. Nehrir, "Evaluating the Benefits of a hybrid solid oxide fuel cell combined heat and power plant for energy sustainability and emissions avoidance," *IEEE Trans. Energy Conv.*, vol. 26, no. 1, pp. 140-148, March 2011.

[2] M. H. Nehrir, C. Wang, K. Strunz, H. Aki, R. Ramakumar, J. Bing, Z. Miao, and Z. Salameh, "A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications," *IEEE Trans. Sust. Energy*, vol. 2, no. 4, pp. 392-403, Oct. 2011.

[3] A. Kashefi Kaviani, G. H. Riahy, and SH. M. Kouhsari, "Optimal design of a reliable hydrogen-based stand-alone wind/PV generating system, considering component outages," *Renewable Energy,* vol. 34, pp. 2380-2390, 2009.

[4] K. Strunz and H. Louie, "Cache energy control for storage: Power system integration and education based on analogies derived from computer engineering." *IEEE Trans. Power Syst.,* vol. 24, no. 1, pp. 12-19, Feb. 2009.

[5] Microgrid Exchange Group, DOE Microgrid Workshop Report, August 2011 [Online]. Available: http://energy.gov/sites/prod/files/Microgrid%20Workshop%20Report%20August%202011.pdf

[6] Homer, National Renewable Energy Laboratory [Online]. Available: http://www.analysis.nrel.gov/homer/

[7] DER-CAM—Distributed energy resources customer adoption model, Lawrence Berkeley National Laboratory [Online]. Available: http://www.der.lbl.gov/der-cam

[8] C. Marnay, G. Venkataramanan, M. Stadler, A. S. Siddiqui, R. Firestone, and B. Chandran, "Optimal Technology Selection and Operation of Commercial-Building Microgrids," *IEEE Trans. Power Systems,* vol. 23, no. 3, pp. 975-982, Aug. 2008.

[9] Lawrence Berkeley National Laboratory, "The carbon dioxide abatement potential of California's mid-sized commercial buildings," January, 2010.

[10] GAMS Development Corporation [Online]. Available: http://www.gams.com/

[11] Stadler Michael, Chris Marnay, Maximilian Kloess, Gonçalo Cardoso, Gonçalo Mendes, Afzal Siddiqui, Ratnesh Sharma, Olivier Megel, Judy Lai, "Optimal Planning and Operation of Smart Grids with Electric Vehicle Interconnection,“ Journal of Energy Engineering, American Society of Civil Engineers (ASCE), Special Issue: Challenges and opportunities in the 21st century energy infrastructure, Volume 138, Issue 2, June 2012.

[12] National Renewable Energy Laboratory, "Innovation for our energy future." [Online]. Available: https://analysis.nrel.gov/homer/includes/downloads/HOMERBrochure_English.pdf

[13] Energy technology cost and performance data, Energy analysis, National Renewable Energy Laboratory [Online]. Available: http://www.nrel.gov/analysis/tech_cost_dg.html

[14] EPRI-DOE handbook of energy storage for transmission and distribution applications, Dec. 2003.

[15] Gas-fired distributed energy resource technology characterizations, National Renewable Energy Laboratory, Nov. 2003.

[16] Compare – Installed costs – Chillers, Sacramento Municipal Utility District [Online]. Available: http://smud.apogee.net/comsuite/content/ces/?utilid=smud&id=1084

[17] National Research Council, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs.* Washington, DC: The National Academies Press, 2004, pp. 98.

[18] ORNL Researchers Design Low-Cost Hydrogen Storage Systems for Stationary Applications, Oak Ridge National Laboratory [Online]. Available: http://www.ornl.gov/sci/eere/PDFs/Cost-fffective_storage_final2.pdf