BNL-108287-2015-JA

Optimal planning and design of hybrid renewable energy systems for microgrids

Jaesung Jung[a*], Michael Villaran[a]

[a] Sustainable Energy Technologies Department, Brookhaven National Laboratory, Upton, NY, USA.
[*]Corresponding author. Tel.: +1-631-344-2643; e-mail: jsjung@bnl.gov (J. Jung)
Postal address: Brookhaven National Laboratory, Sustainable Energy Technologies Department, Mail Stop 179B - P.O. Box 5000, Upton, NY 11973-5000 USA.

Abstract

This paper presents a technique for optimal planning and design of hybrid renewable energy systems for microgrid applications. The Distributed Energy Resources Customer Adoption Model (DER-CAM) is used to determine the optimal size and type of distributed energy resources (DERs) and their operating schedules for a sample utility distribution system. Using the DER-CAM results, an evaluation is performed to evaluate the electrical performance of the distribution circuit if the DERs selected by the DER-CAM optimization analyses are incorporated. Results of analyses regarding the economic benefits of utilizing the optimal locations identified for the selected DER within the system are also presented. The actual Brookhaven National Laboratory (BNL) campus electrical network is used as an example to show the effectiveness of this approach. The results show that these technical and economic analyses of hybrid renewable energy systems are essential for the efficient utilization of renewable energy resources for microgird applications.

Keywords

Hybrid renewable energy system, distributed energy resource, microgrid, microgrid planning, microgrid design, DER placement, DER-CAM

1. Introduction

Renewable energy is regarded as an appealing alternative to conventional power generated from fossil fuel [1-2]. This is leading to increasingly significant levels of distributed renewable energy generation being installed on existing distribution circuits. Although renewable energy generation brings many advantages, circuit problems can be created due to the intermittency and variability of the renewable energy resources.

A hybrid renewable energy system, consisting of two or more renewable energy sources used together, mitigates the intermittent nature of renewable energy resources, improves the system efficiency, and provides greater overall balance in the energy supply. However, hybrid renewable energy systems have received limited attention due to the complexities of achieving optimal planning and design. Conventional approaches can sometimes result in renewable energy combinations that are over-sized or not properly planned or designed [3].

A microgrid is a group of interconnected loads and Distributed Energy Resource (DER) generation that acts as a single controllable entity with respect to the grid, but with the capability to connect and disconnect from the grid. Microgrids are increasingly being considered to enhance a local grid reliability, resiliency, quality, and efficiency. Furthermore, microgrids can offer the ability to increase the effectiveness of renewable energy and to help implement net-zero buildings, campuses and communities [4]. For these reasons, techniques for optimal planning and design of hybrid renewable energy systems for microgrids are studied in this paper.

The technical and economic analyses of hybrid renewable energy systems for microgrids are essential for the efficient utilization of renewable energy resources. Several software tools are introduced and compared to

analyze the electrical, economic and environmental performance of hybrid renewable energy systems [5-7]. A survey of recent studies on this subject area shows that various hybrid renewable energy systems have been investigated using Hybrid Optimization of Multiple Energy Resources (HOMER) [8-26]. However, not many comparable studies can be found that utilize the Distributed Energy Resources Customer Adoption Model (DER-CAM). The survey also shows that DER-CAM in some cases is considered to be a preferable tool for the purpose of hybrid renewable energy system design modeling, mainly due to the robust and flexible three-level optimization algorithm, hourly time step and other scale considerations, but particularly due to the several successful applications with modeling microgrid systems [5]. Thus, DER-CAM is selected for this study.

DER-CAM is a tool that was developed by Lawrence Berkeley National Laboratory (LBNL) to help optimize the selection and operation of distributed energy resources on a utility distribution system [27]. The main objective of DER-CAM is to minimize either the annual costs or the CO_2 emissions of providing energy services to the modeled site, including utility electricity and natural gas purchases, plus amortized capital and maintenance costs for any DER investments. The key inputs into the model are the customer's end-use energy loads, energy tariff structures and fuel prices, and a user defined list of preferred equipment investment options. The program outputs the optimal DER and storage adoption combination, and an hourly operating schedule, as well as the resulting costs, fuel consumption, and CO_2 emissions.

However, the focus of the DER-CAM model is primarily an economic analysis that does not in any way take into consideration the electrical distribution circuit performance that will result from implementation of the microgrid. Further research is required to develop an integrated analytical tool that will combine the economic optimization capabilities of the DER-CAM model together with an electrical system performance modeling and analysis tool for a more complete and comprehensive analysis of DER and microgrid applications. For example, it is possible that the cost-optimized configuration of DER will not provide acceptable electrical performance on the distribution circuit and adverse impacts, such as voltage violations could result. In this paper, further analysis is performed to include an evaluation of the electrical performance of the distribution circuit after development of a microgrid based on the output of the DER-CAM analytical tool.

Furthermore, the physical placement of DER within the microgrid is vital in order to obtain the full benefits from the microgrid and improve both the efficiency and reliability of the system [28-29]. Therefore, this paper also analyzes the economic benefit of the optimal location of DER in the system in conjunction with the optimized economic and environmental outputs from a DER-CAM analysis. The results will show how the microgrid performance can be further enhanced by properly locating DER.

The paper is organized as follows: following this introduction, Section 2 presents the DER-CAM results on the optimal size, type and operation schedules for DER adoption for a sample microgrid. It also shows an estimate of the total annual energy costs and total annual CO_2 emissions when the selected DERs are adopted. In Section 3, the electrical performance of the distribution circuit is evaluated using Distribution Engineering Workstation (DEW) software after initial development of a microgrid based on the output of the DER-CAM analytical tool. In addition, the effects of varying the locations of DER in the system are compared in Section 4. Finally, the findings of the study are summarized in Section 5.

2. Economic and environmental performance evaluation of hybrid renewable energy systems using DER-CAM

2.1. Site selection

One representative feeder on the Brookhaven National Laboratory (BNL) campus electrical network was selected for the study because it includes large research and office buildings as well as the 0.5 MW Northeast Solar Energy Research Center (NSERC) solar PV research array, as shown in Figure 1. The NSERC has been supplying a maximum of 518kW-dc of solar generation directly into the BNL distribution system since May of 2014. The total load on this feeder typically ranges between 2.5 MW and 5.5 MW. The NSERC solar PV array is the only non-emergency generation on the feeder. The largest single facility load on the feeder is the Center for Functional Nanomaterials (CFN), which is a mix of research facilities, laboratories, and offices. The remainder of the loads on the feeder consists of small industrial buildings (pumps, air conditioning, ventilation,

lighting, etc.), small research laboratories, and office and administration buildings.

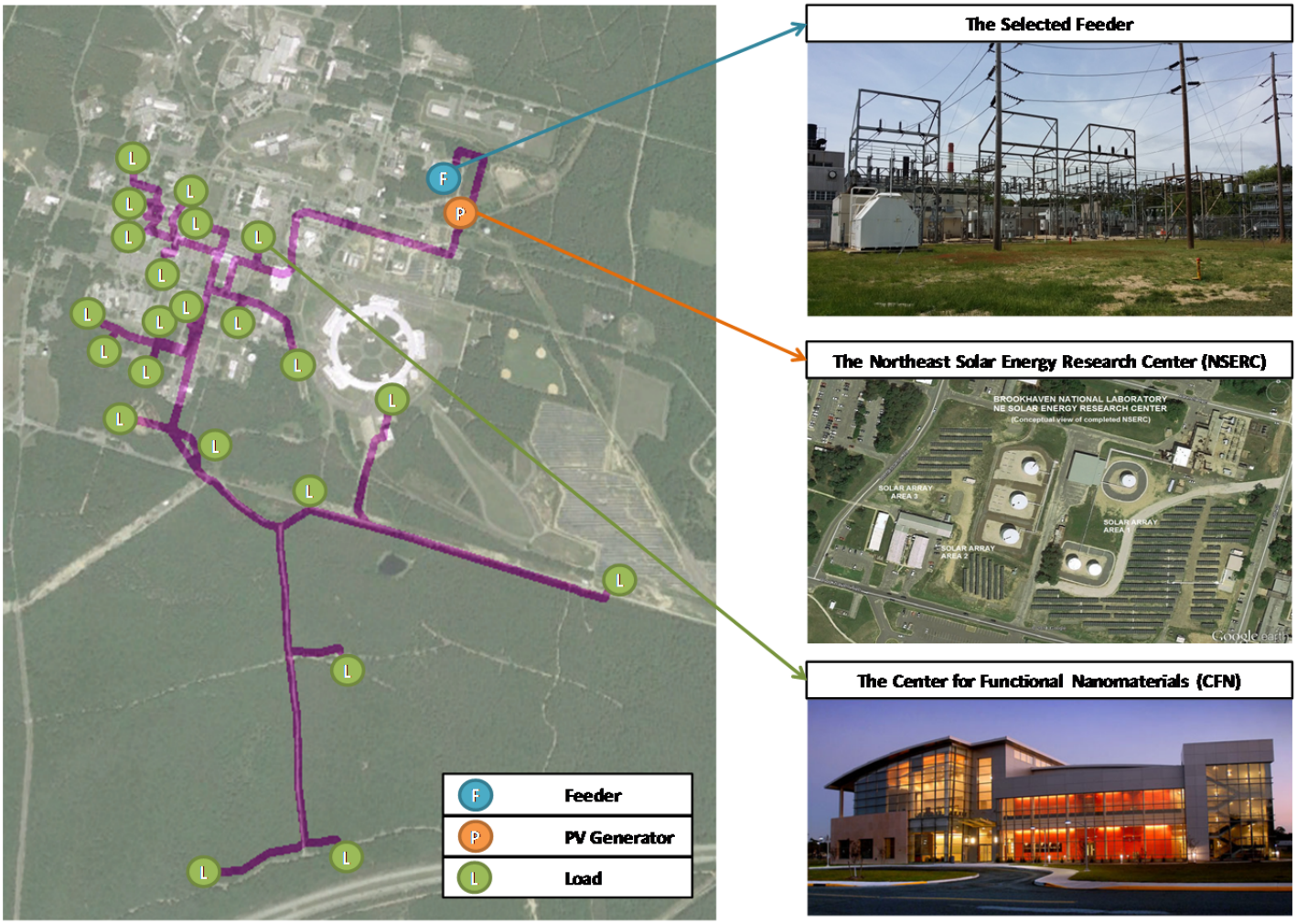


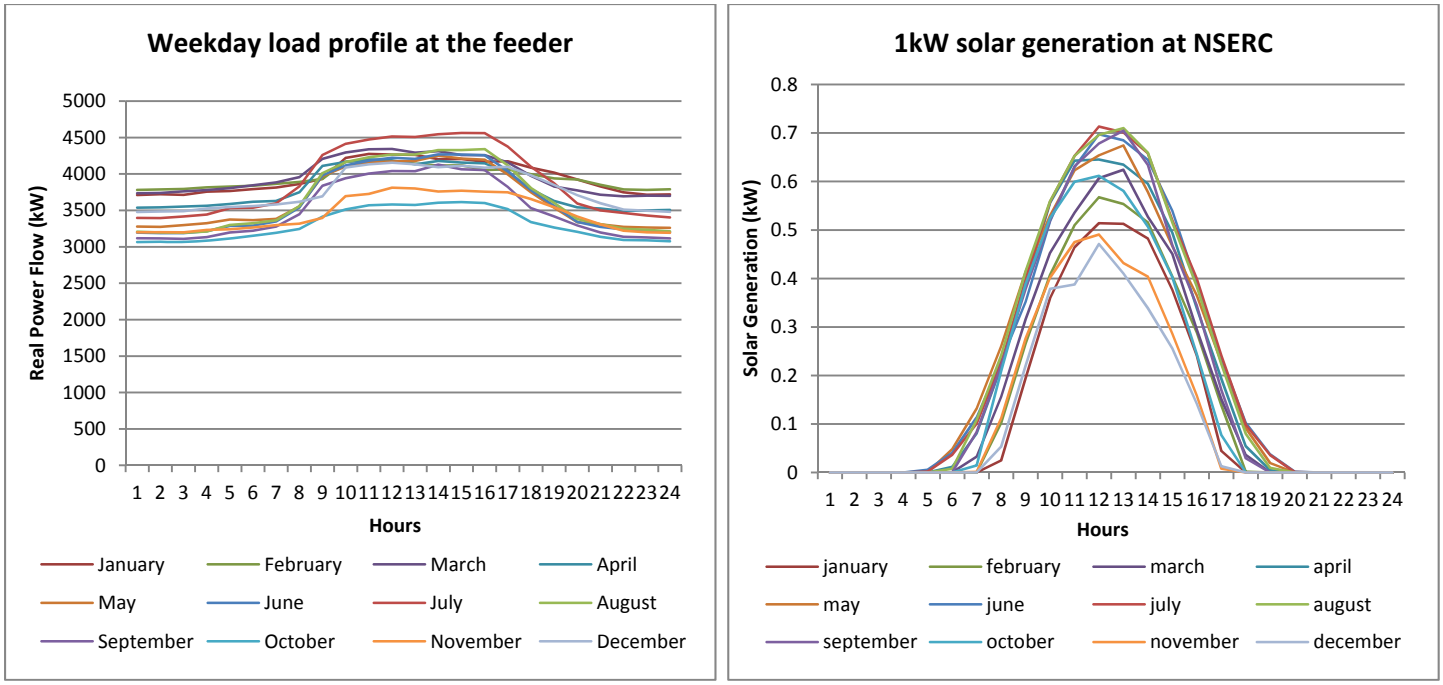
Figure 1 the selected feeder for the simulation

The major buildings, operating units, and research facilities that are supplied by this feeder, in most cases, are metered at their service entrance. In some of the larger facilities such as the CFN, the entire facility is metered, but individual feeders within the facility may also be tracked for purposes of monitoring energy usage. Most of the meters at BNL are part of an Advanced Metering Infrastructure (AMI) system. However, not all of the parameters that can be measured by these devices are gathered and stored by the AMI system at this time. At the present time, load data are collected and stored automatically by the AMI system, typically every 15 minutes. Several of the older buildings on the site may still be monitored by manual energy meters; these load data are recorded manually, typically on a monthly basis.

As previously mentioned, the BNL NSERC is also connected to this feeder. The NSERC is a research and test facility specifically developed for evaluating and commercializing innovative new technologies that will advance the use of solar energy, particularly in the northeast, and facilitate integration into the electric grid. The NSERC currently has a 518kW grid-connected solar photovoltaic research array available for field-testing equipment under actual northeastern weather conditions, and is fully instrumented with research-grade monitoring equipment to provide high resolution (1 sec.), time-stamped data sets for research purposes.

2.2. Key inputs to DER-CAM

The load profile at the feeder and a normalized 1kW solar generation profile at NSERC are used as inputs for DER-CAM as shown in Figure 2 (a) and (b), respectively. Furthermore, the standard commercial PSEG-LI electric rate is used for the local energy tariff structure [30]. The reference data provided by DER-CAM are used for the fuel and equipment investment prices.



(a) Weekday load profile at the feeder (b) 1kW solar generation at NSERC

Figure 2 key input data into DER-CAM

A multi-objective approach was used in this study by considering the minimization of both the annual costs and CO_2 emissions. Every optimization run in the multi-objective study is a tradeoff between the cost and environmental functions. A weighting factor is input to DER-CAM to indicate the user's preference for minimizing cost (weighting factor = 1.0) or emissions (weighting factor = 0.0). The weighting factor used will impact the DER combination recommended by DER-CAM. The program also considers the relative investment cost of each DER being considered and factors this into the recommended mix. For example, even though the costs of utility-scale energy storage investments continue to decrease, it still remains an expensive technology. Consequently, in this study energy storage, which is relatively higher cost than the other DER options selected, would typically not be economically viable when cost minimization options alone are being evaluated (weighting factor = 1.0). For illustrative purposes in this study, a weighting factor of 0.75 is used, indicating 75% weight is given to minimizing annual cost and 25% weight is given to minimizing CO_2 emissions. Two cases are simulated:

Non-microgrid case – most economical and environmental solution for the BNL campus to operate with a supply of utility power and without being a microgrid
Microgrid case – most economical and environmental solution for the BNL campus to operate as a microgrid, including island mode

2.3. DER-CAM results and discussions

2.3.1. Non-microgrid case results

Table 1 shows the annual energy cost and CO_2 emission savings, by investment, for the Non-microgrid case. The optimal technology adoption reduces the total annual energy cost by $143,702 and the total annual CO_2 emissions by 1,109,336 kg. Figure 3 shows the DER-CAM investment results for the Non-microgrid case. DER-CAM suggests an optimal mix of 1,285 kW PV generation and 250 kW diesel generation together with a 477 kW stationary battery at the selected site.

Figure 4 shows the detailed hourly electricity operating schedule during the peak day in July for the Non-microgrid case. The base load is supplied by utility power purchase and the increase load above the base load is supplied by PV and diesel generation. The stationary battery is charged during non-peak time and then supplies the stored electrical energy back to the system during the peak operating time.

Table 1 the annual costs and CO_2 emissions savings by the investment for the Non-microgrid case

	Reference Case (no investment)	Non-microgrid Case (investment)	Reduction
Total Annual Energy Costs ($)	$4,073,282	$3,929,580	*- $143,702*
Total Annual CO_2 emissions (kg)	16,656,949 kg	15,547,613 kg	*- 1,109,336 kg*

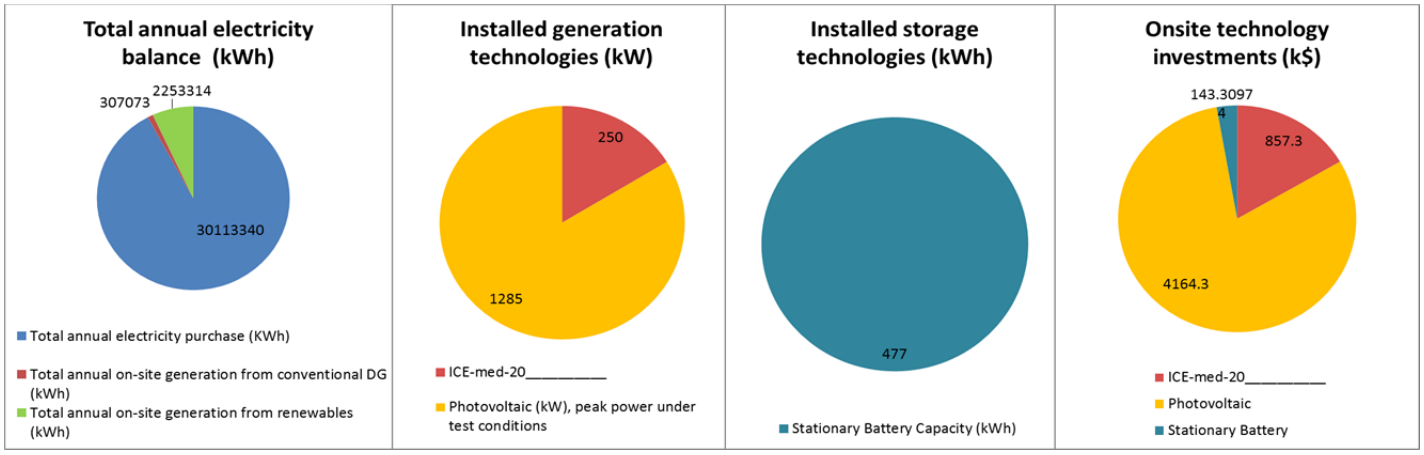


Figure 3 DER-CAM investment results for the Non-microgrid case

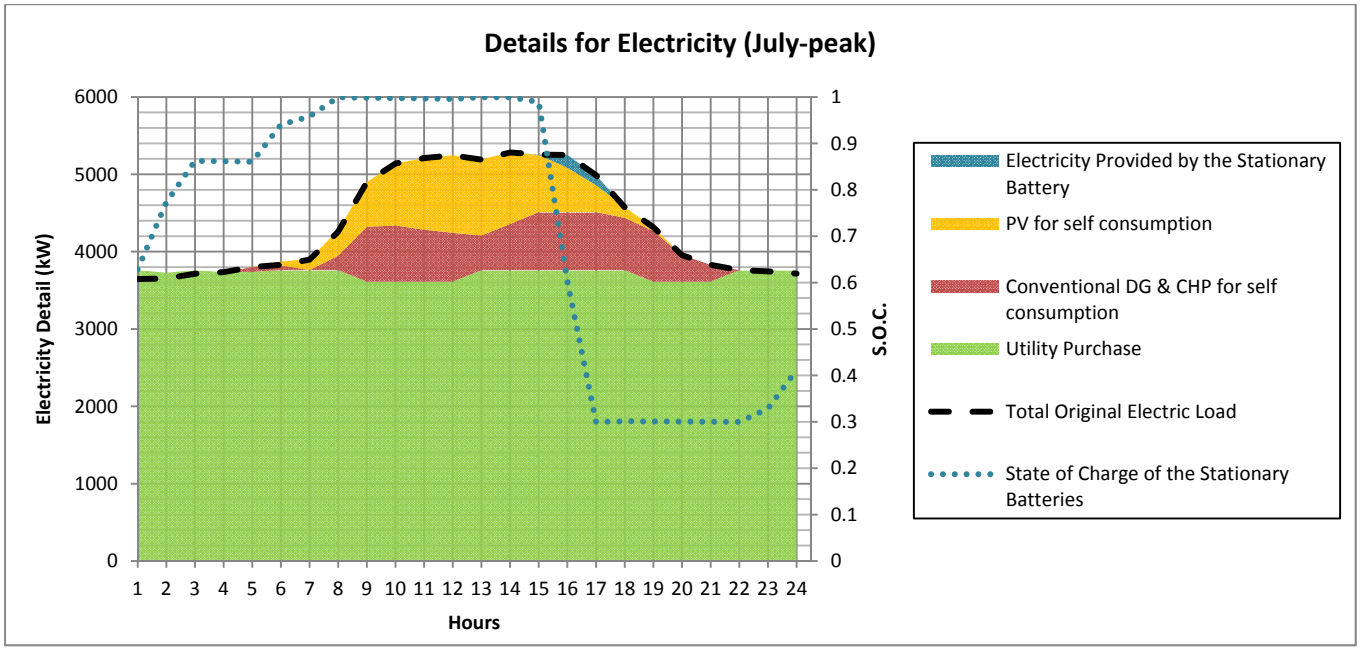


Figure 4 the detail electricity operation during peak day in July for the Non-microgrid case

2.3.2. Microgrid case results

The microgrid is a group of interconnected loads and DER generation that acts as a single controllable entity with respect to the grid, but with the capability to connect and disconnect from the grid. To simulate the microgrid case in DER-CAM, we select the one peak day, as in the previous case, but then assume that the supply of electricity from the utility is not available. Therefore, all electricity required by the microgrid on the peak day has to be supplied from the local DG. Table 2 shows the annual energy cost and CO_2 emissions savings, by investment, for the microgrid case. The microgrid technology adoption increased the total annual energy cost by $159,977, however, the total annual CO_2 emissions are reduced by 5,925,155 kg. Although the microgrid offers the potential for tremendous environmental benefits, the overall economic challenge must be overcome before their full potential can be realized.

Figure 5 shows the DER-CAM investment results for the microgrid case. DER-CAM suggests an optimal mix of 7110 kW PV generation and 570 kW diesel generation together with a 969 kW stationary battery at the selected site.

Figure 6 shows the detail hourly electricity operating schedule during the peak day in July. This is the result of grid-connected operation. The PV generation period partially coincides with the peak demand on that day. At the time of peak demand, the microgrid's on-site generation covers all the load demand; during the remainder of the afternoon local DG charges the stationary battery. When PV generation is insufficient to meet the microgrid's load demand, the local diesel generation, utility purchase, and the stationary battery are used to make up any difference.

Table 2 the annual costs and CO_2 emissions savings by the investment for the microgrid case

	Reference Case (no investment)	Microgrid Case (investment)	Reduction
Total Annual Energy Costs ($)	$4,073,282	$4,233,259	*+ $159,977*
Total Annual CO_2 emissions (kg)	16,656,949 kg	10,731,794 kg	*- 5,925,155 kg*

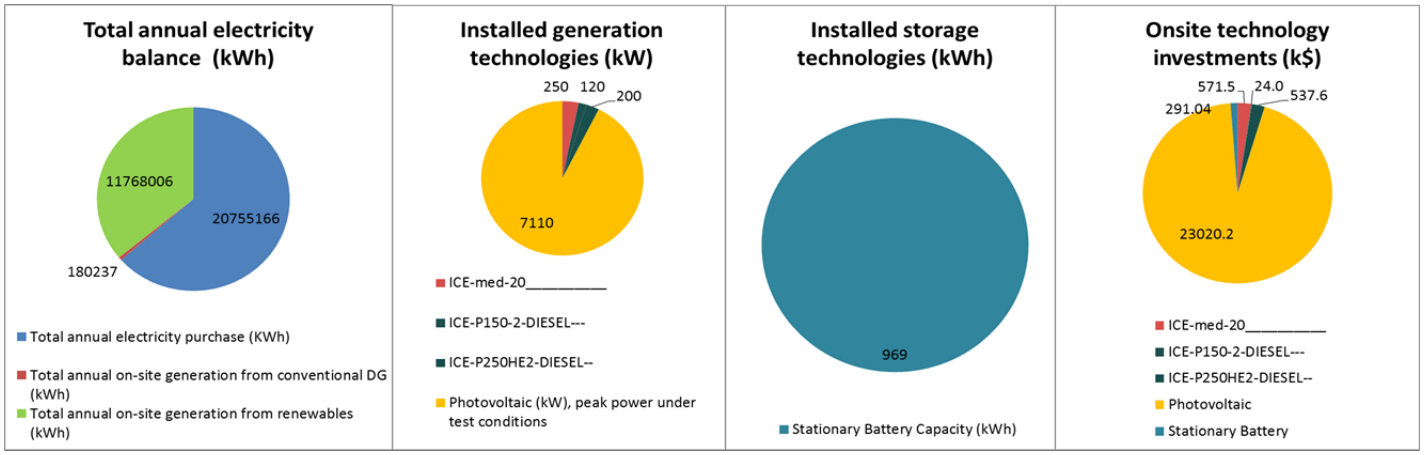


Figure 5 DER-CAM investment results for the microgrid case

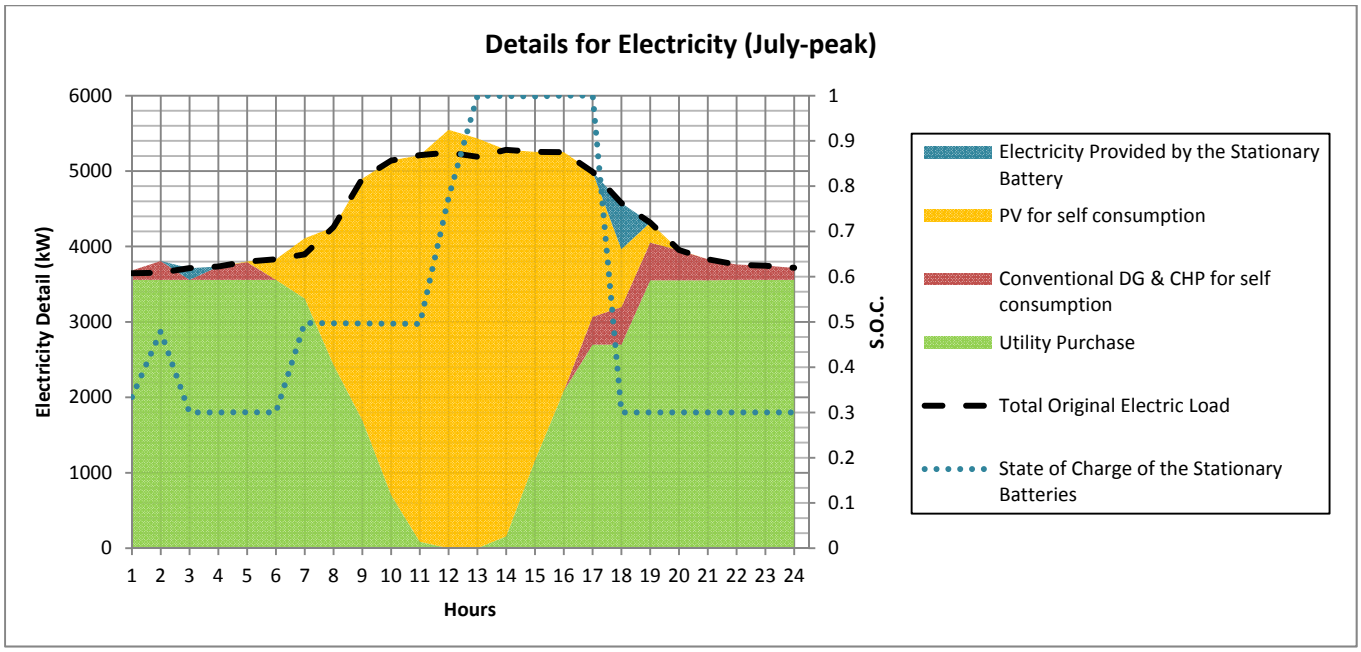


Figure 6 the detail electricity operation during peak day in July for the microgrid case

2.3.3. Discussions

The results show that DER-CAM can provide information on the optimal size, type and operation schedules for DER adoption based on specific site load and price information, and performance data for available equipment options. The model also provides an estimate of the total annual energy costs and total annual CO_2 emissions when the selected DERs are adopted. In this study, DER-CAM can offer the ability to increase the effectiveness of renewable energy and to help implement net-zero buildings, campuses and communities.

However, the focus of this model is primarily an economic analysis that does not take into consideration the electrical distribution circuit performance that will result from implementation of the microgrid. Further

research is required to develop an integrated analytical tool that will combine the economic optimization capabilities of the DER-CAM model together with an electrical system performance modeling and analysis tool for a more complete and comprehensive analysis of DER and microgrid applications. For example, it is possible that the cost-optimized configuration of DER will not provide acceptable electrical performance on the distribution circuit and adverse impacts, such as voltage violations could result. Therefore, further analysis is performed in the next section to evaluate the electrical performance of the distribution circuit after development of a microgrid based on the output of the DER-CAM analytical tool.

3. Electrical performance evaluation of hybrid renewable energy systems using DEW

3.1. DER adoption for electrical performance evaluation

Figure 7 shows the developed DEW model using the selected feeder to evaluate the electrical performance of the cost-optimized configuration of DER obtained from DER-CAM. The circuit model is derived from actual data. It is a 13.8 kV, Y-connected circuit supplying power to several major buildings, operating units, and research facilities. The time-varying loads are estimated from averaged hourly AMI measurements, hourly customer kWh load data, and monthly kWh load data processed by load research statistics to create hourly loading estimates for each customer [31-32].

Initially the selected DERs from the DER-CAM analysis are randomly placed in the developed DEW model without making any power system violations such as voltage and overloading violations [33-34]. The NSERC has been supplying a maximum of 518kW-dc of solar generation directly into this feeder, and there are plans to expand the solar array in the near future at the same location. Therefore, the location of PV generation is fixed at the current NSERC location. The initial locations of energy storage and diesel generator are also shown in Figure 7.

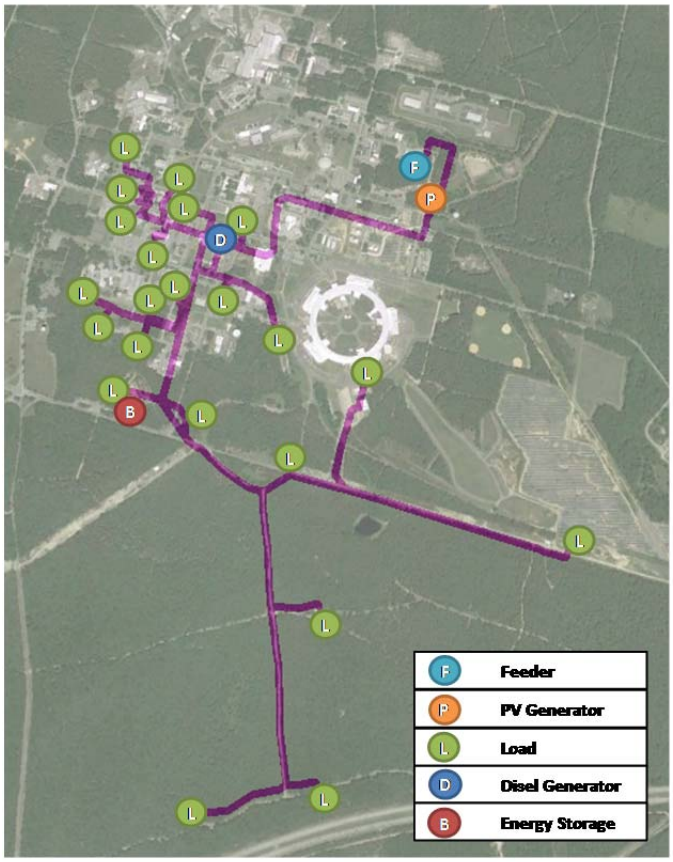
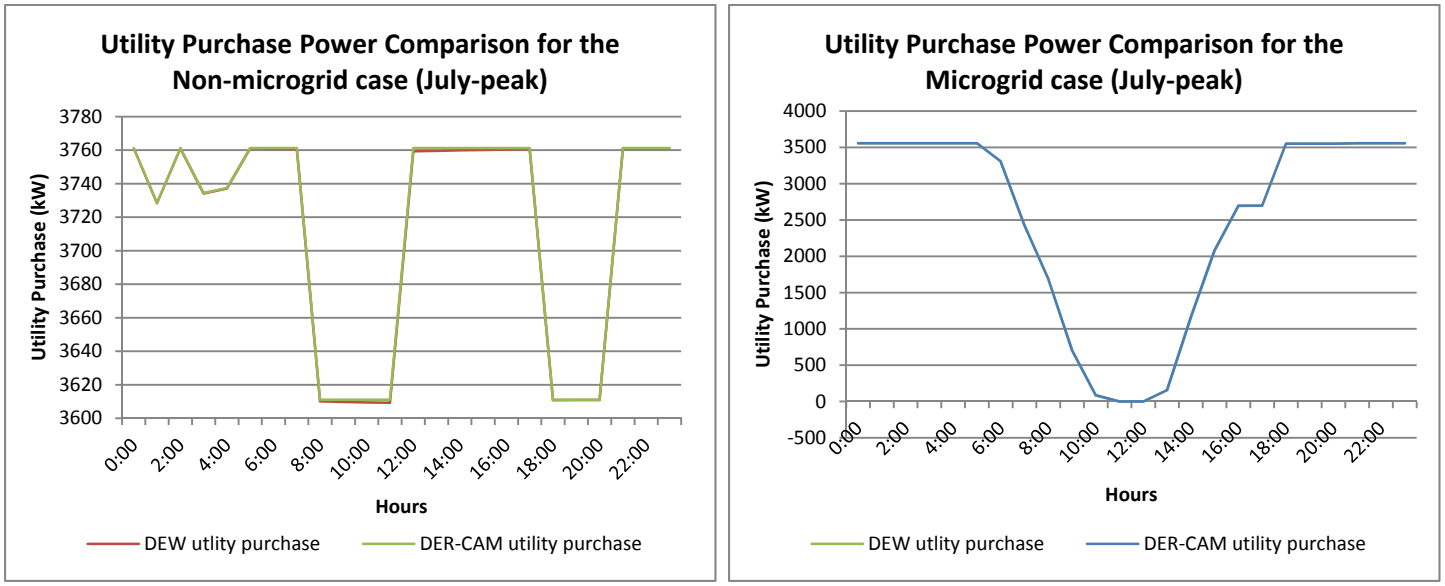


Figure 7 DER adopted location at the selected feeder

Furthermore, the DER-CAM-suggested hourly electricity operating schedules of PV generators, diesel generators, and energy storage are applied into the circuit to evaluate the electrical performance. Results show there are no changes in power system violations after adopting the recommended DERs. Figure 8 shows the

utility electricity purchase comparison between DER-CAM and DEW results. The results show that the power purchased from the utility is almost identical. This means that the DER-CAM-suggested operating schedule of DERs works well and it didn't require purchasing more or less power from the utility. However, the DEW results show a little lower utility power purchase because it includes the power system loss reduction benefits provided by DER adoption, which is not considered in DER-CAM. Thus, the economic benefit resulting from power system loss reduction will be added into the DER-CAM economic performance results in next section.

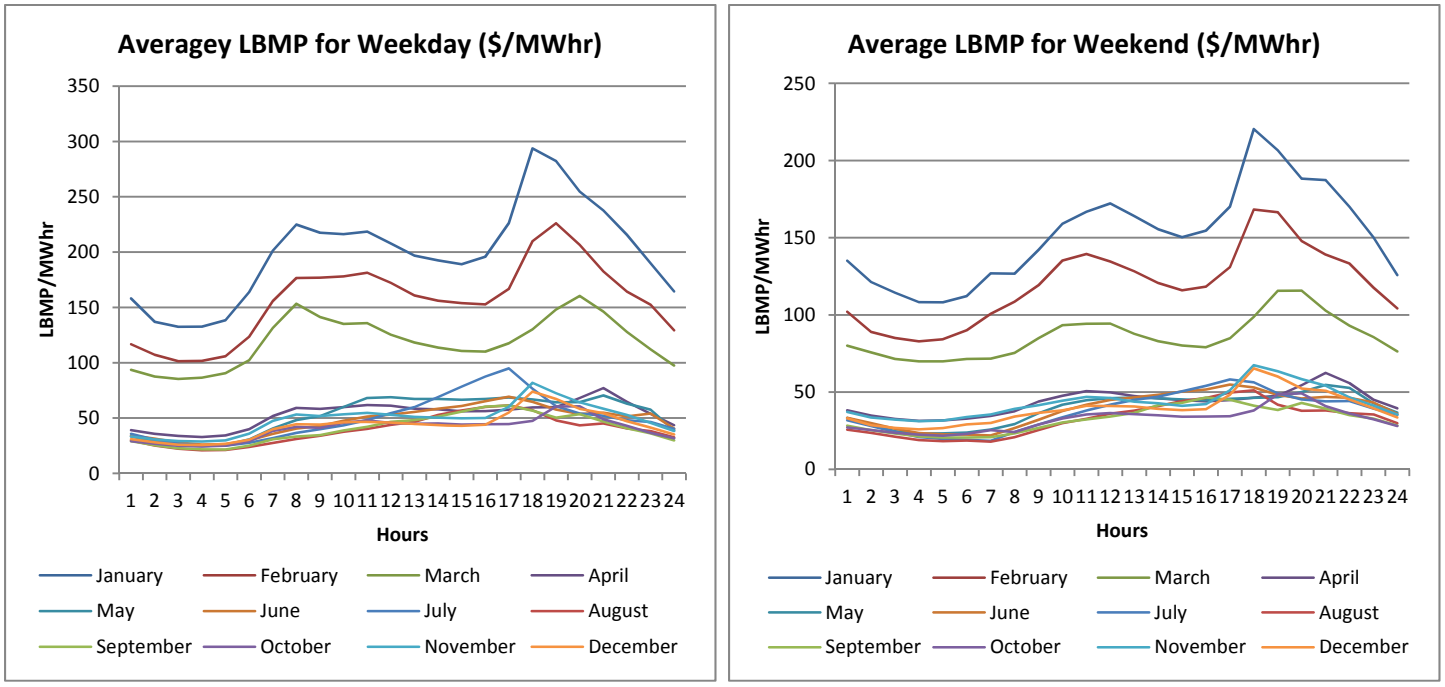


(a) utility purchase power comparison for the non-microgrid case (b) utility purchase power comparison for the microgrid case

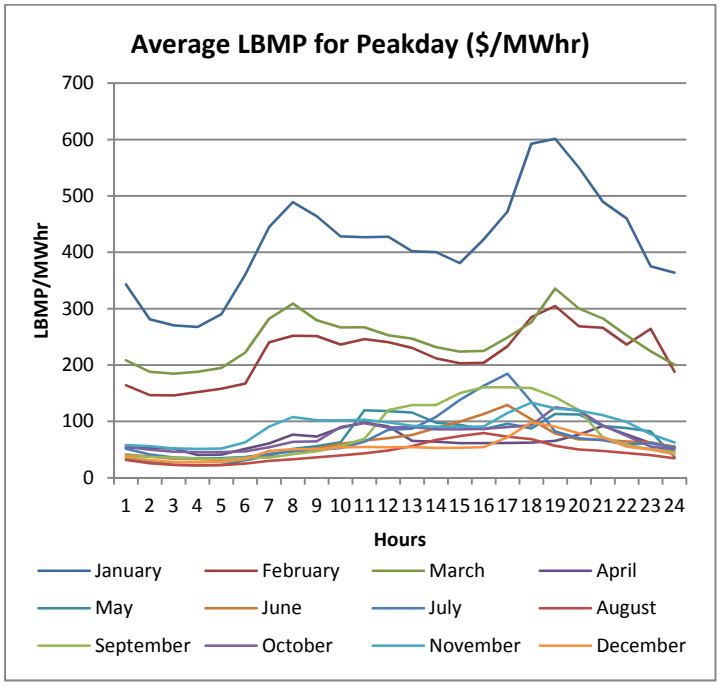
Figure 8 utility purchase power comparison between DER-CAM and DEW results for the non-microgrid and microgrid case during peak day in July

3.2. Economic performance evaluation of power system loss reduction by DER adoptions

The hourly Location Based Marginal Prices (LBMP) for the Long Island load zone in New York State is used to calculate the economic benefit of power system loss reduction by DER adoptions, as shown in Figure 9 [35]. Average LBMP of all weekdays and weekends except peakday during the month is used for weekday and weekend calculation. Average LBMP of three peak days during the month is used for the peakday calculation. In these figures (Figures 9 (a), (b), and (c)), a much higher LBMP is observed in the first three months of the year (January, February, and March) than for the other remaining months of the year.



(a) Average LBMP for weekday (b) Average LBMP for weekend



(c) Average LBMP for peakday

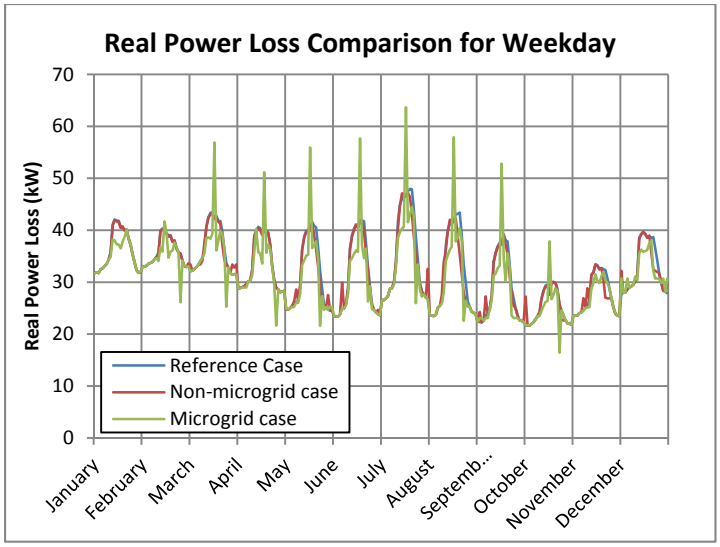
Figure 9 the hourly LBMP for the long island load zone in New York area [35]

Figures 10 through 12 show the real power system loss comparison for weekday, weekend, and peakday, respectively. Each figure includes real power system loss for the specific day and at their monthly price. The number of days shown in Table 3 is assumed to calculate the monthly power system loss. The monthly power system loss is calculated by multiplying the specific day with its number in Table 3.The cost is then calculated by multiplying the monthly power system loss with the LBMP in Figure 9.

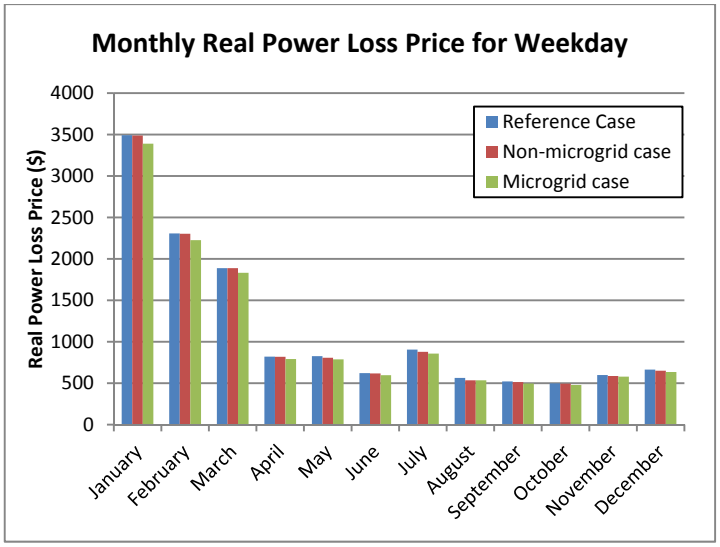
In these figures, the microgrid case shows the most power system loss reduction during the winter season, however, it increases the loss during the summer season when PV generation is peak. This is a result of some redundancy in the PV generation. Although the microgrid case increases the losses during peak generation time, the overall power system loss reduction benefit is the greatest in the microgrid case for weekdays and weekends. The non-microgrid case is the most beneficial for peakday operation. Furthermore, the first three months have higher real power system loss prices than other months because of higher LBMP in these months.

Table 3 number of day for each month

	Weekday number	Weekend number	Peakday number
January	20	8	3
February	17	8	3
March	18	10	3
April	19	8	3
May	20	8	3
June	17	10	3
July	20	8	3
August	18	9	3
September	18	9	3
October	20	8	3
November	18	9	3
December	19	9	3

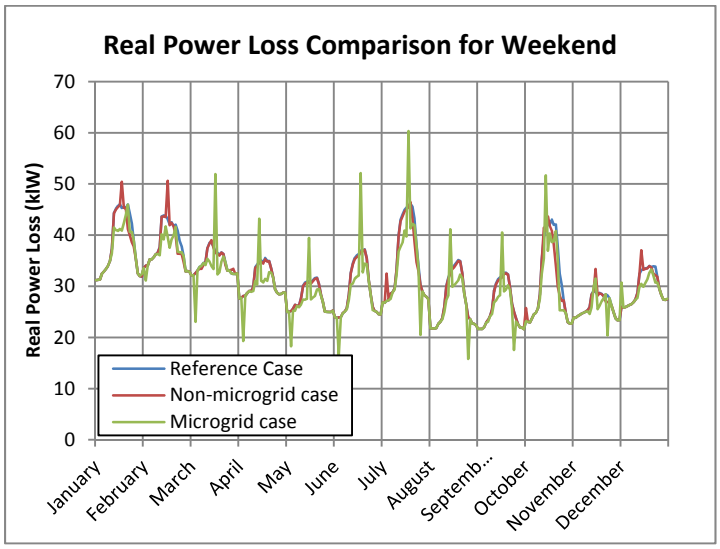


(a) Real power system loss for weekday

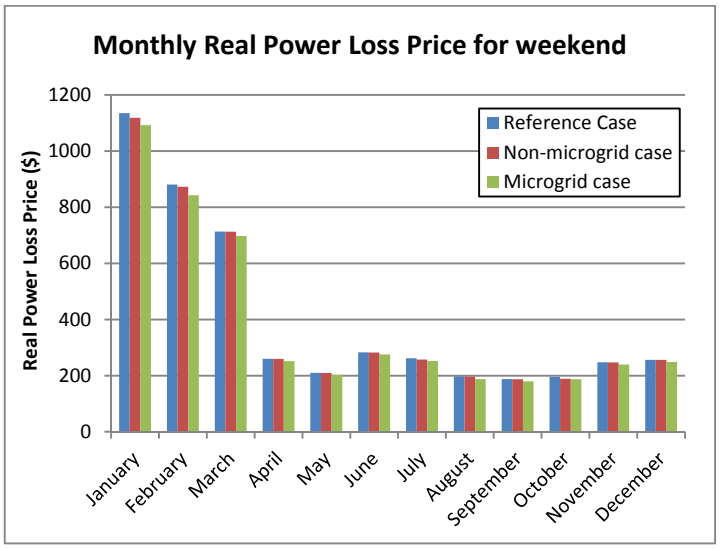


(b) Monthly real power system loss price for weekday

Figure 10 real power system loss comparison for weekday

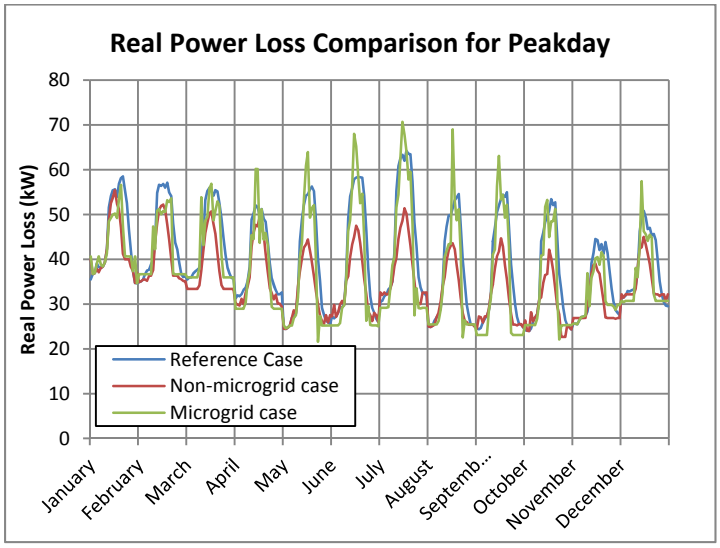


(a) Real power system loss for weekend

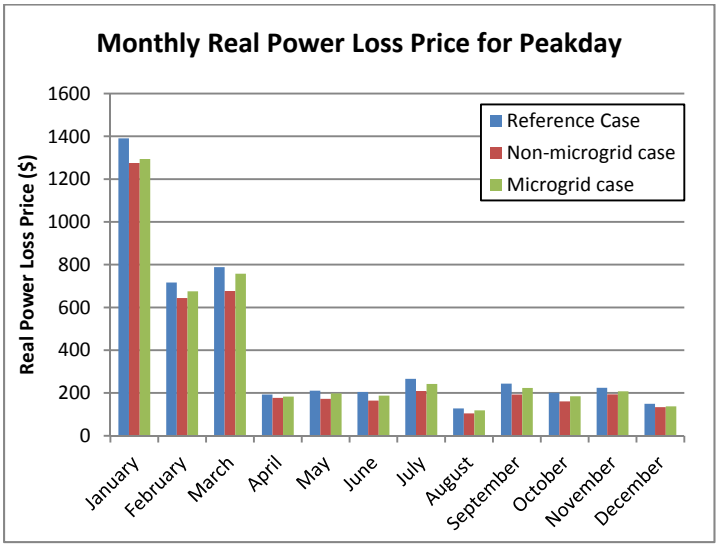


(b) Monthly real power system loss price for weekend

Figure 11 real power system loss comparison for weekend



(a) Real power system loss for peakday



(b) Monthly real power system loss price for peakday

Figure 12 real power system loss comparison for peakday

Figure 13 shows the monthly real power system loss price for the whole year, which is sum of Figure 10 (b), Figure 11 (b), and Figure 12 (b). It shows that the first three months have higher real power system loss prices

than other months, similar to that observed in the previous figures. It also shows that the microgrid case shows the most power system loss cost reduction. The non-microgrid case is also able to reduce the cost more than the reference case. Table 4 shows the total economic performance evaluation of power system loss reduction by DER adoptions. The non-microgrid case reduces the cost from power system loss by $777 and the microgrid case reduces the cost from power system loss by $977. More DER investments show greater cost reduction in real power system loss. The annual energy cost by combining DER-CAM results with power system loss reduction is reduced by $144,479 in the non-microgrid case but still increases by $159,000 in the microgrid case.

After completing the electrical performance of the hybrid renewable energy systems by applying the DER-CAM investments, the microgrid case still shows an economic disadvantage. However, one of the biggest benefits of the microgrid application is to enhance a local grid's reliability, resiliency, power quality, and efficiency. This study shows that the microgrid case is able to improve the efficiency and shows how much economic benefit is obtained from this. In the future, further analysis is required to estimate the other microgrid benefits (reliability, resiliency, and quality) to encourage more microgrid applications. In the next section, this paper will continue to investigate how much economic benefit of the optimal location of DERs in conjunction with the optimized economic and environmental outputs from DER-CAM analysis can provide.

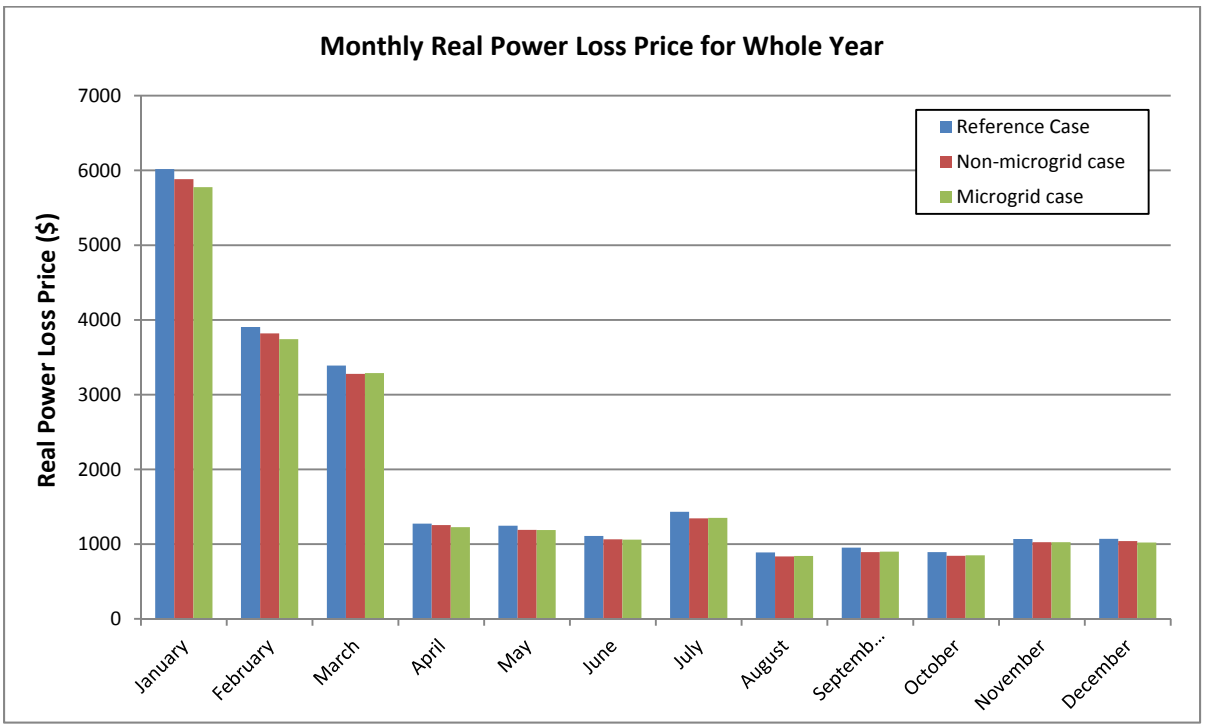


Figure 13 monthly real power loss price for whole year

Table 4 Economic performance evaluation of power system loss reduction by DER adoptions

	Reference Case	DER-CAM Results	Reduction	Power System Loss Reduction	Total Reduction
Non-microgrid Case	$4,073,282	$3,929,580	*- $143,702*	*- $777*	*- $144,479*
Microgrid Case		$4,233,259	*+ $159,977*	*- $977*	*+ $159,000*

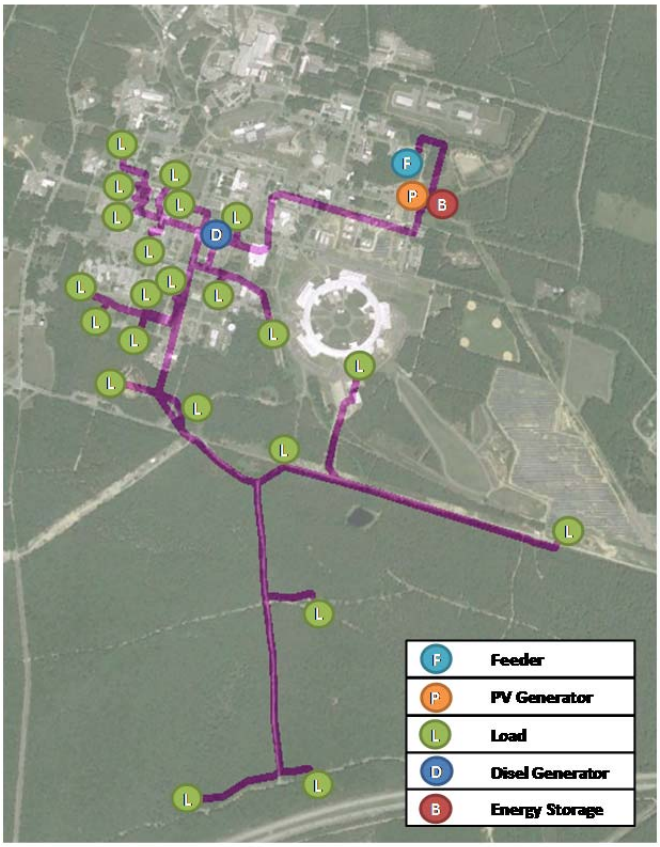
4. Economic performance evaluation of the optimal placement of DER

4.1. Optimizing DER placement

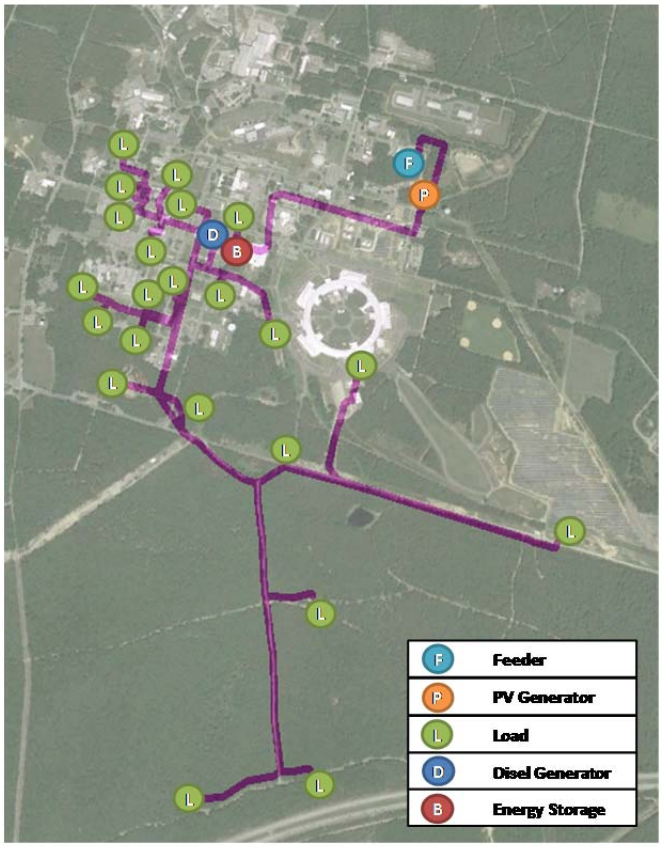
Initially, the selected DERs from the DER-CAM analyses are randomly placed in the developed DEW model without making any power system design violations such as voltage and overloading, as described in the previous section. In this analysis, the combination of DERs among the selected locations is varied in order to try to optimize the locations where the DERs are deployed and quantify the resulting economic benefits. Again, the location of the PV generation remains fixed at the current NSERC location. Four different combinations of microgrid cases are then simulated:

Microgrid case – initial selection as shown in Figure 7 (reference case)
Microgrid-PV case – energy storage is located where the PV generation is located as shown in Figure 14 (a)
Microgrid-Big Load case – energy storage and diesel generator are located where the big load is located as shown in Figure 14 (b)
Microgrid-Small Load case – energy storage and diesel generator are located where the small load is located as shown in Figure 14 (c)

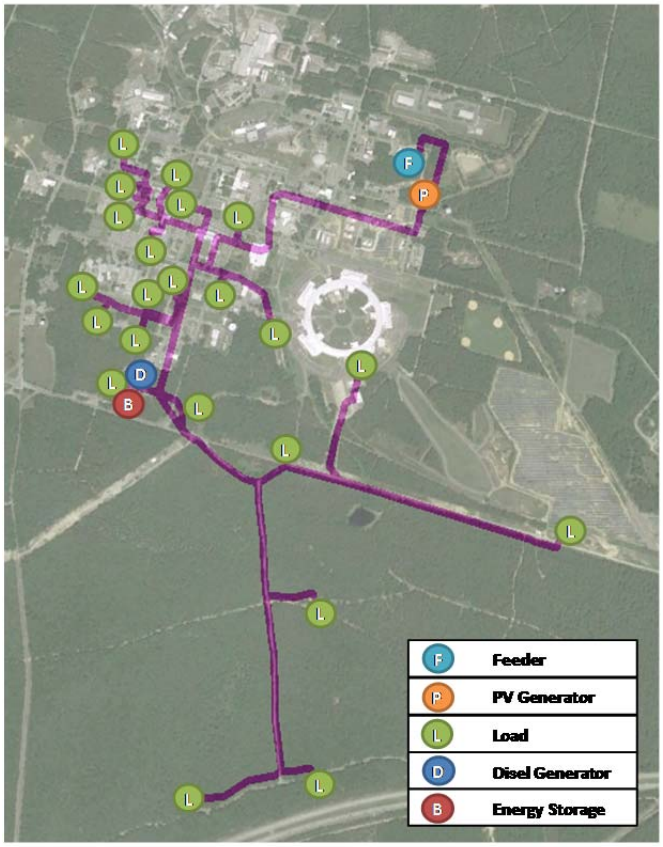
The detailed locations of DER for each case are shown in Figure 14. The Microgrid-PV case is selected to see the effects when the storage is located close to the charging source. The energy storage is mainly charged by PV generators according to the DER-CAM suggested hourly electricity operating schedule. The Microgrid-Big Load case is selected to show the effects when minimizing the power delivery losses. The Microgrid-Small Load case is selected to compare the results with the Microgrid-Big Load case.



(a) DER placement for Microgrid-PV case



(b) DER placement for Microgrid-Big Load case



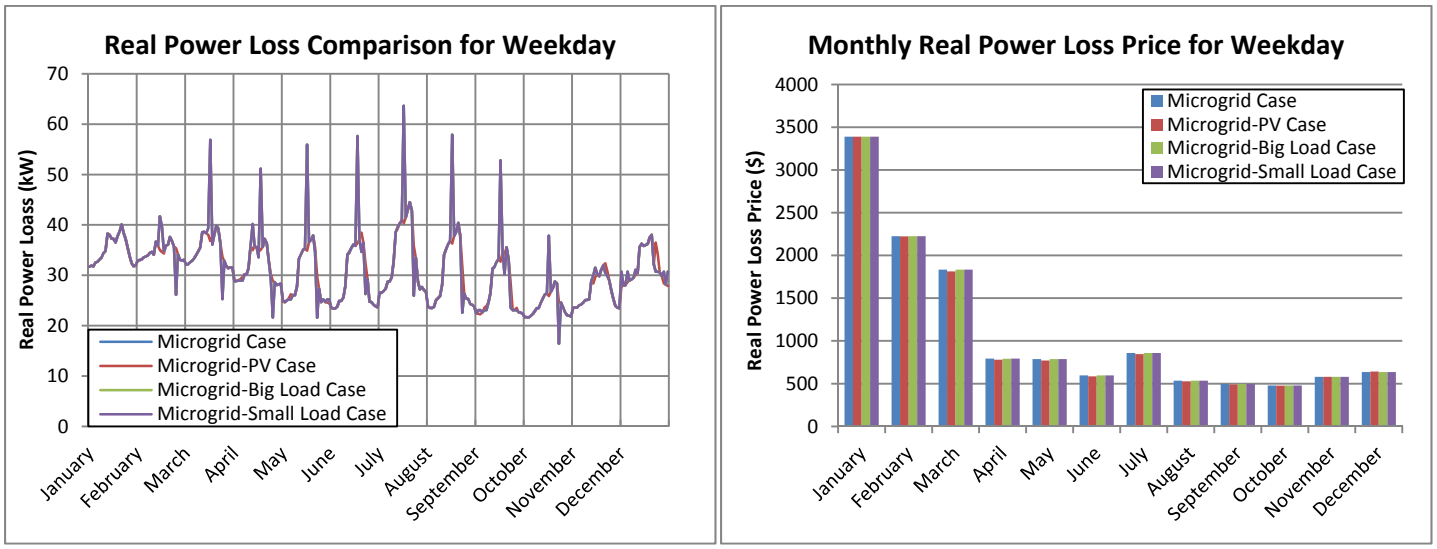
(c) DER placement for Microgrid-Small Load case

Figure 14 DER placement at the selected feeder

4.2. Economic performance evaluation of the optimal placement of DER

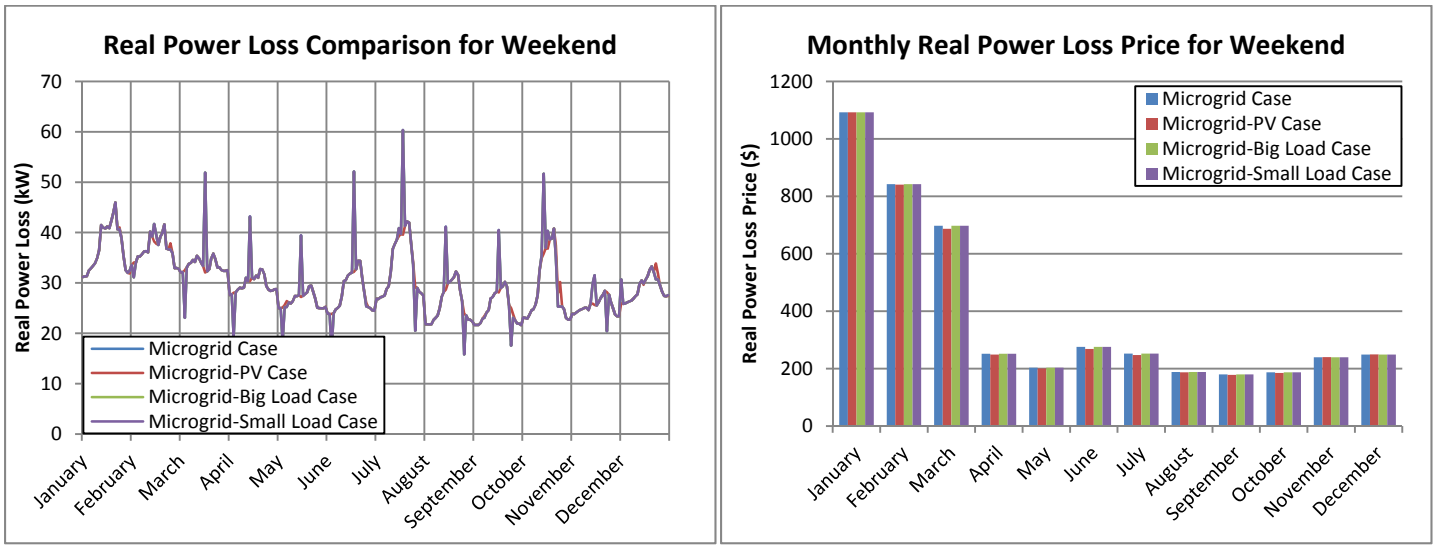
Figures 15 and 16 show the real power system loss comparison for different combinations of DERs for weekday, weekend, and peakday, respectively. Each figure includes the real power system loss for the specific day and at their monthly price. The monthly real power loss price is calculated in same way as described in the previous section. The first three months have higher real power system loss prices than the other months because of higher LBMP in these months, as was noted in the previous analysis.

The overall power system loss reduction benefit is the greatest in the Microgrid-PV case. This shows that the greatest system benefit is realized when the energy storage is located closest to the charging source. There is not much difference found between the Microgrid-Big Load and Microgrid-Small Load cases. The reason for this in the case of the selected circuit is that it is physically so small that the delivery loss effect is negligible. However, the case where the DERs are located close to the big load shows a little more benefit than the case where the DERs are located close to the small load. The trend that the loss increases during peak generation time is not found in the Microgrid-PV case analysis. This is because the redundant PV generation is used to charge the energy storage completely.



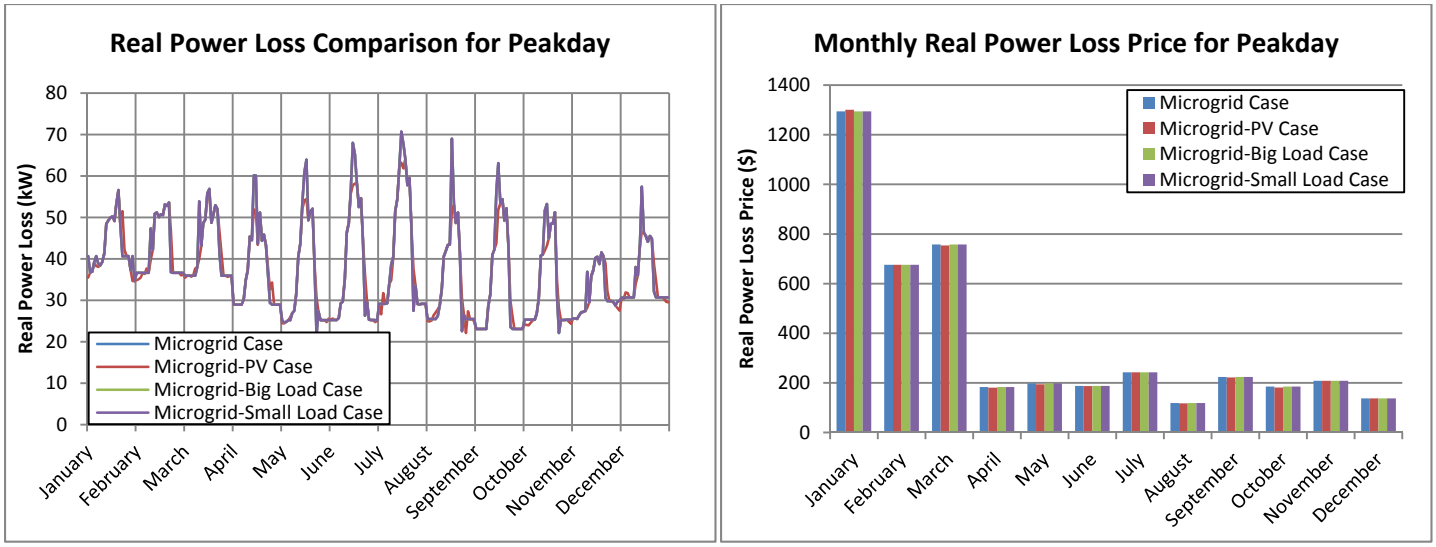
(a) Real power loss comparison for weekday (b) Monthly real power loss price for weekday

Figure 15 real power system loss comparison of the optimal plcaement of DER for weekday



(a) Real power loss comparison for weekend (b) Monthly real power loss price for weekend

Figure 16 real power system loss comparison of the optimal plcaement of DER for weekend



(a) Real power loss comparison for peakday (b) Monthly real power loss price for peakday

Figure 17 real power system loss comparison of the optimal plcaement of DER for peakday

Figure 18 shows the monthly real power system loss price for a whole year, which is sum of Figure 15 (b), Figure 16 (b), and Figure 17 (b). Again, this analysis shows that the first three months have higher real power system loss prices than other months such as shown observed in the analyses in previous sections. It also indicates that the Microgrid-PV case shows the greatest power system loss price reduction. However, the other cases analyzed are not able to reduce the power system loss significantly compared to the microgrid case. Table 5 shows the total economic performance evaluation of power system loss reduction for various combinations of DERs. The Microgrid-PV case reduces the cost from power system loss by $1,111, which is the annual energy cost achieved by combining DER-CAM results with power system loss reduction increases by $158,866. The improvement in the other cases was found to be nearly the same. Therefore, this study shows that energy storage located closest to the PV generator in this selected circuit is the most beneficial configuration and the effect of diesel generator location is negligible in this case because of its small size.

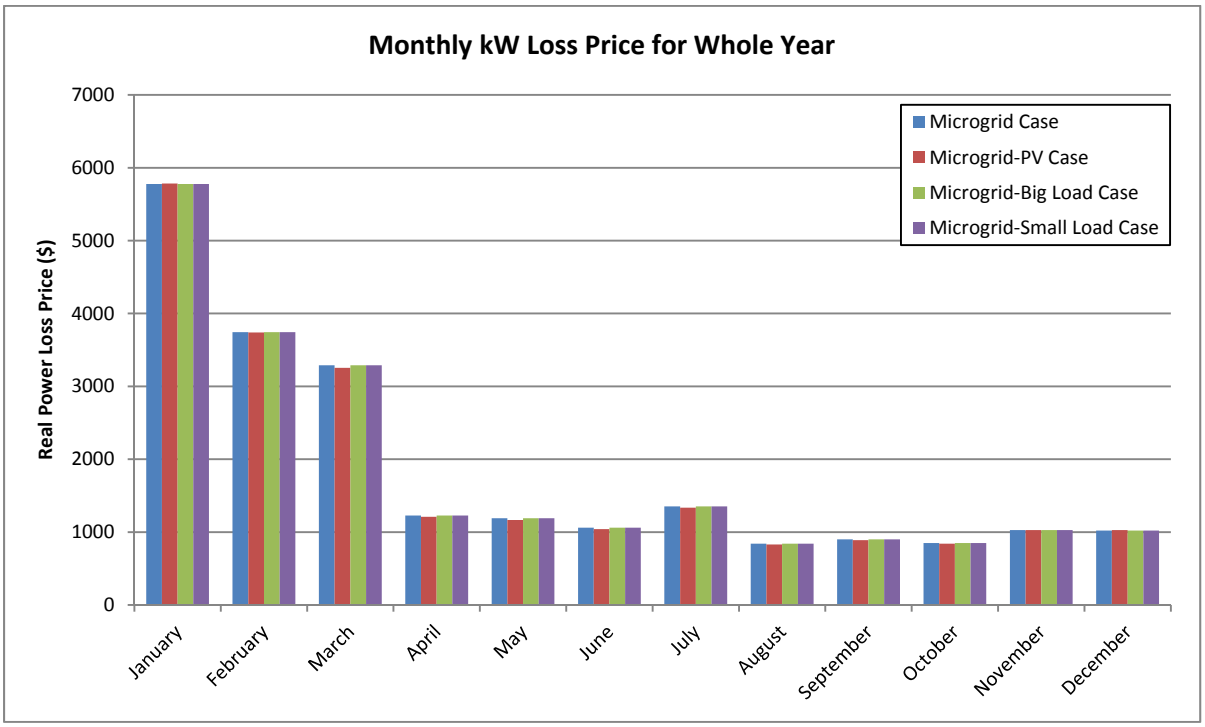


Figure 18 monthly real power loss price of the optimal placement of DER for whole year

Table 5 Economic performance evaluation of power system loss reduction of the optimal palcement of DER

	Reference Case	DER-CAM Results	Reduction	Power System Loss Reduction	Total Reduction
Microgrid Case	$4,073,282	$4,233,259	***+ $159,977***	***- $977***	***+ $159,000***
Microgrid-PV Case				***- $1,111***	***+ $158,866***
Microgrid-Big Load Case				***- $978***	***+ $158,999***
Microgrid-Big Load Case				***- $977***	***+ $159,000***

5. Conclusions

Techniques for optimal planning and design of hybrid renewable energy systems were investigated for configuring an example power distribution grid as a microgrid. First, the DER-CAM tool is used to help optimize the selection and operation of distributed energy resources on a utility distribution system. Then, an evaluation is conducted to determine the electrical performance of the distribution circuit after development of a microgrid based on the output of the DER-CAM analytical tool. This paper also analyzes the economic benefits of the optimal location of the selected DERs within the system. These technical and economic analyses of hybrid renewable energy systems are essential for the efficient utilization of renewable energy resources for microgird applications.

The results of the analyses show that DER-CAM can provide information on the optimal size, type and operational schedules for DER adoption based on the estimate of the total annual energy costs and total annual CO_2 emissions. It demonstrates the capability of optimization analyses to increase the effectiveness of renewable energy integration and to help implement net-zero buildings, campuses and communities.

Further analysis was performed using DEW to develop an integrated analytical tool that combines the economic optimization capabilities of the DER-CAM model together with an electrical system performance modeling and analysis tool for a more complete and comprehensive analysis of DER and microgrid applications. In the power system demonstration example analyzed, results show that the adopted DERs are able to improve the efficiency of the system, and the economic benefits of the enhancements are quantified.

Finally, this paper demonstrates the increased economic benefits of the optimal location of DERs in conjunction with the optimized economic and environmental outputs from DER-CAM analysis. It was shown that the location of energy storage closest to the PV generator in this selected circuit is the most beneficial configuration and the effect of diesel generator location is negligible because of its small size.

After completing the electrical performance of the hybrid renewable energy systems by applying the DER-CAM investments, the microgrid case still shows economic disadvantages. However, the biggest benefits of adopting the microgrid application, i.e., enhancement of a local grid's reliability, resiliency, power quality, and efficiency, are not quantified in this analysis. This study shows that the microgrid application is able to improve the efficiency of a system. However, addressing the increased application-specific value provided by these other important benefits remains a challenge for future study: how to weigh these grid-related microgrid benefits including reliability, resiliency, and quality improvements, against the economic disadvantages when the customer considers the microgrid investment options.

6. Acknowledgment

The authors would like to thank the Microgrid R&D team at Lawrence Berkeley National Laboratory for providing the DER-CAM training and technical assistance in this study.

7. Reference

[1] United States Department of Energy, SunShot Vison Study, Report DOE/GO-102012-3037, Feb. 2012. Available at: < http://www1.eere.energy.gov/solar/sunshot/vision_study.html>.

[2] United States Department of Energy, 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply, Report DOE/GO-102008-2567, Jul. 2008. Available at: <http://energy.gov/eere/wind/20-wind-energy-2030-increasing-wind-energys-contribution-us-electricity-supply>

[3] Y.S. Mohammed, M.W. Mustafa, N. Bashir, Hybrid renewable energy systems for off-grid electric power: Review of substantial issues, Renew. Sust. Energy Rev., 35 (2014) 527-539.

[4] M. Soshinskaya, W.H.J. Crijns-Graus, J.M. Guerrero, J.C. Vasquez, Microgrids: Experiences, barriers and success factors, Renew. Sust. Energy Rev., 40 (2014) 659-672.
[5] G. Mendes, C. Ioakimidis, P. Ferrao, On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools, Renew. Sust. Energy Rev., 15 (2011) 4836-4854.
[6] D. Markovic, D. Cvetkovic, B. Masic, Survey of software tools for energy efficiency in a community, Renew. Sust. Energy Rev., 15 (2011) 4897-4903.
[7] S. Sinha, S.S. Chandel, Review of software tools for hybrid renewable energy system, Renew. Sust. Energy Rev., 32 (2014) 192-205.
[8] Y. Kalinci, Alternative energy scenarios for Bozcaada island, Turkey, Renew. Sust. Energy Rev., 45 (2015) 468-480.
[9] M.S. Ngan, C.W. Tan, Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia, Renew. Sust. Energy Rev., 16 (2012) 634-647.
[10] W.M. Amutha, V. Rajini, Techno-economic evaluation of various hybrid power systems for rural telecom, Renew. Sust. Energy Rev., 43 (2015) 553-561.
[11] A. Ghasemi, A. Asrari, M. Zarif, S. Abdelwahed, Techno-economic analysis of stand-alone hybrid photovoltaic-diesel-battery systems for rural electrification in eastern part of Iran – A step toward sustainable rural development, Renew. Sust. Energy Rev., 28 (2013) 456-462.
[12] R. Sen, S.C. Bhattacharyya, Off-grid electricity generation with renewable energy technologies in India: An application of HOMER, Renew. Energy, 62 (2014) 388-398.
[13] A. Asrari, A. Ghasemi, M.H. Javidi, Economic evaluation of hybrid renewable energy systems for rural electrification in Iran – A case study, Renew. Sust. Energy Rev., 16 (2012) 3123-3130.
[14] M.A.M. Ramli, A. Hiendro, S. Twaha, Economic analysis of PV/diesel hybrid system with flywheel energy storage, Renew. Energy, 78 (2015) 398-405.
[15] H. Kim, S. Baek, E. Park, H.J. Chang, Optimal green energy management in Jeju, South Korea – On-grid and off-grid electrification, Renew. Energy, 69 (2014) 123-133.
[16] S.M. Shaahid, L.M. Al-Hadhrami, M.K. Rahman, Review of economic assessment of hybrid photovoltaic-diesel-battery power systems for residential loads for different provinces of Saudi Arabia, Renew. Sust. Energy Rev., 31 (2014) 174-181.
[17] O. Hafez, K. Bhattacharya, Optimal planning and design of a renewable energy based supply system for microgrids, Renew. Energy, 45 (2012) 7-15.
[18] M.A.M. Ramli, A. Hiendro, K. Sedraoui, S. Twaha, Optimal sizing of grid-connected photovoltaic energy system in Saudi Arabia, Renew. Energy, 75 (2015) 489-495.
[19] E.D. Giannoulis, D.A. Haralambopoulos, Distributed Generation in an isolated grid: Methodology of case study for Lesvos – Greece, Appl. Energy, 88 (2011) 2530-2540.
[20] M. Mudasser, E.K. Yiridoe, K. Corscadden, Cost-benefit analysis of grid-connected wind-biogas hybrid energy production, by turbine capacity and site, Renew. Energy, 80 (2015) 573-582.
[21] T. Ma, H. Yang, L. Lu, A feasibility study of a stand-alone hybrid solar-wind-battery system for a remote island, Appl. Energy, 121 (2014) 149-158.
[22] Z. Chmiel, S.C. Bhattacharyya, Analysis of off-grid electricity system at Isle of Eigg (Scotland): Lessons for developing countries, Renew. Energy, 81 (2015) 578-588.
[23] A. Demiroren, U. Yilmaz, Analysis of change in electric energy cost with using renewable energy sources in Gokceada, Turkey: An island example, Renew. Sust. Energy Rev., 14 (2010) 323-333.
[24] A.M. Abdilahi, A.H.M. Yatim, M.W. Mustafa, O.T. Khalaf, A.F. Shumran, F.M. Nor, Feasibility study of renewable energy-based microgrid system in Somaliland's urban centers, Renew. Sust. Energy Rev., 40 (2014) 1048-1059.
[25] D. Chade, T. Miklis, D. Dvorak, Feasibility study of wind-to-hydrogen system for Arctic remote locations – Grimsey island case study, Renew. Energy, 76 (2015) 204-211.
[26] G. Bekele, B. Palm, Feasibility study for a standalone solar-wind-based hybrid energy system for application in Ethiopia, Appl. Energy, 87 (2010) 487-495.
[27] M. Stadler, M. Groissbock, G. Cardoso, C. Marnay, Optimizing Distributed Energy Resources and building retrofits with the strategic DER-CAModel, Appl. Energy, 132 (2014) 557-567.

[28] D. Zhu, R.P. Broadwater, K.-S. Tam, R. Seguin, H. Asgeirsson, Impact of DG Placement on Reliability and Efficiency With Time-Varying Loads, IEEE Trans. Power Syst., 21 (2006) 419-427.
[29] C. Gamarra, J.M. Guerrero, Computational optimization techniques applied to microgrids planning: A review, Renew. Sust. Energy Rev., 48 (2015) 413-424.
[30] PSEG-LI electric rate. Available at: <https://www.psegliny.com/page.cfm/AboutUs/ServiceRates>
[31] R.P. Broadwater, A. Sargent, A. Yarali, H.E. Shaalan, J. Nazarko, Estimating substation peaks from load research data, IEEE Trans. Power Del., 12 (1997) 451-456.
[32] A. Sargent, R.P. Broadwater, J.C. Thompson, J. Nazarko, Estimation of Diversity and KWHR-to-Peak-KW Factors From Load Research Data, IEEE Trans. Power Syst., 9 (1994) 1450-1456.
[33] J. Jung, H. Asgeirsson, T. Basso, J. Hambrick, M. Dilek, R. Seguin, R. Broadwater, Evaluation of DER Adoption in the Presence of New Load Growth and Energy Storage Technologies. In: 2011 PES general meeing, Detroit, Michigan, USA; 2011.
[34] J. Jung, Y. Cho, D. Cheng, A. Onen, R. Arghandeh, M. Dilek, R.P. Broadwater, Monte Carlo analysis of Plug-in Hybrid Vehicles and Distributed Energy Resource growth with residential energy storage in Michigan, Appl. Energy, 108 (2013) 218-235.
[35] The New York Independent System Operator (NYISO) Location Based Marginal Prices (LBMP). Available at: < http://www.nyiso.com/public/markets_operations/market_data/pricing_data/index.jsp>