Increasing the Value of Customer-Owned PV Systems Using Batteries

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Executive Summary

Consumers in the U.S. have become accustomed to a highly reliable source of electricity. In the process, they have become vulnerable to unexpected power outages. A recent analysis by LBL estimated that a 1 hour outage during a summer afternoon cost the average customer approximately $3 for a residential customer $1,200 for a small commercial and industrial customer, and $8,200 for a large commercial and industry customer [9]. As a result, the annual cost of power interruptions in the U.S. is significant, costing the U.S. economy tens of billions of dollars per year. In addition, major outages, such as the one that occurred on August 14, 2003 on the East Coast, are very costly and disruptive. Rather than being an isolated incident, however, experts expect that these unexpected outages will continue to occur. This suggests that consumers need to protect themselves from power outages.

The paper examines how storage can be profitably combined with customer-owned photovoltaic (PV) systems. Results indicate that customer-owned PV systems can have value to both consumers and the utility. Both residential and commercial customers can obtain outage protection with less storage when combined with PV, thus resulting in a capital cost savings; the amount of savings depends upon the customer's critical load and the amount of PV. Commercial customers may also achieve additional utility bill savings by switching from firm to non-firm rate structures, providing for their own power needs when their load is curtailed.

There is also value to utilities. In addition to the well-documented T&D system benefits of PV alone, utilities may be able to dispatch customer-owned batteries for a short duration of time (a few minutes) to manage loads in the event of system emergencies. This may prevent a catastrophic outage while using only a fraction of the batteries' capacity. This would allow the battery systems to continue to provide consumers with outage protection in the event the outage still occurs.

There are several areas of potential future work. They include:

- Quantification of the benefit that consumers have more energy production during an outage with PV and storage during certain times of the day than with storage alone
- More accurate accounting of PV output uncertainty and battery characteristics
- Evaluation of the feasibility of commercial customers switching from firm to non-firm rates
- Quantification of the economic and technical potential of utilities to control customer-owned battery systems in the event of a system emergency

Background

> *"The 14 August 2003 blackout may have been the largest in history, zapping more total wattage and affecting more customers than any before, but if history is any guide, it won't be the last. 'These kinds of outages are consistent with historical statistics, and they'll keep happening,' says John Doyle, professor of control and dynamical systems, electrical engineering, and bioengineering at the California Institute of Technology in Pasadena. 'I would have said that this one was overdue.'"* [11]

Consumers in the U.S. have become increasingly accustomed to a highly reliable source of electricity. As a result, outages such as the one that occurred on August 14, 2003 caught many people unprepared and cost between $4 and $6 billion [11].

There are a variety of theories about what causes major outages in general. Experts do agree, however, that the recommendations of the U.S.-Canada task force report will not eliminate large blackouts. Stopping them will require that engineers fundamentally change the way they operate the power system [11].

This leaves consumers in a risky position. Consumers assume that electric power will always be available when it is needed and yet the utility grid is likely to experience large-scale outages in the future.

Introduction

Distributed PV generation technologies provide relief to stressed power grids by providing peak time capacity [5] and [6]. Figure 1 illustrates a typical customer-sited PV system. One way that the benefits of this system could be increased is by combining it with battery storage as shown in Figure 2.

The PV + storage installation shown in Figure 2 has the potential to provide three specific benefits:

1. Providing critical load generation for the customer should outages occur (red line)
2. Reduce peaks to either reduce demand charges (if customer-dispatched) or to reduce system peaks (if utility dispatched) – (blue line)
3. The utility could dispatch the storage to prevent outages (gray line).

The result is that the addition of battery storage can increase the value of customer-owned PV from both customer and utility perspectives.

Table 1 summarizes the benefits accruing from each component of a PV + storage installation. The PV system alone benefits the customer via energy savings and demand savings (commercial customers) and also brings value to a utility's T&D system. The addition of storage or load control can bring extra value to commercial customers if driven to reduce local demand. The same storage/control can bring additional value to a utility if driven to maximize T&D capacity and prevent emergencies. Finally, storage benefits the customer by providing outage recovery insurance and benefits the utility by preventing potential outages.

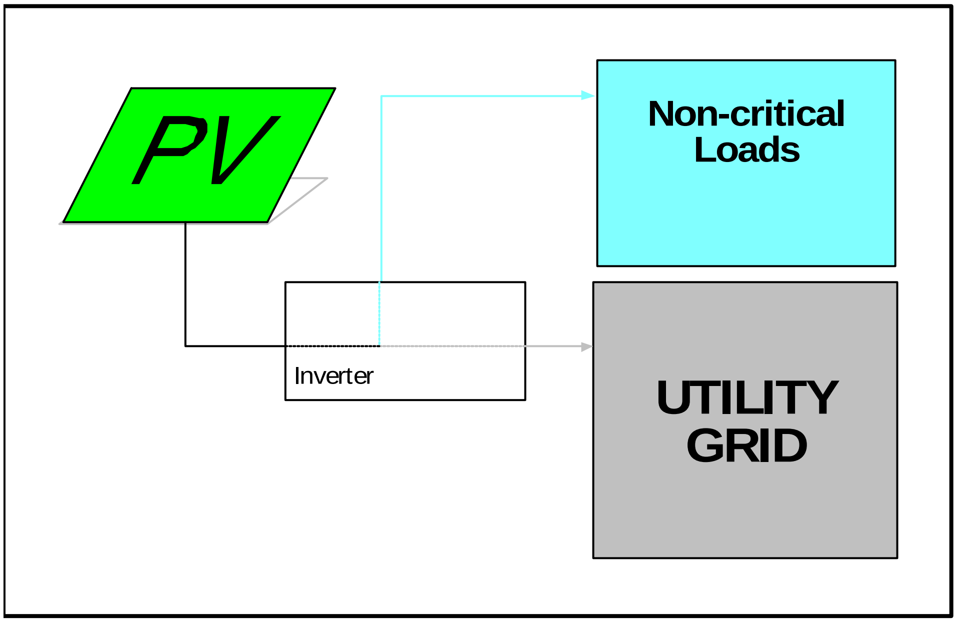

Figure 1. Customer-sited PV installation.

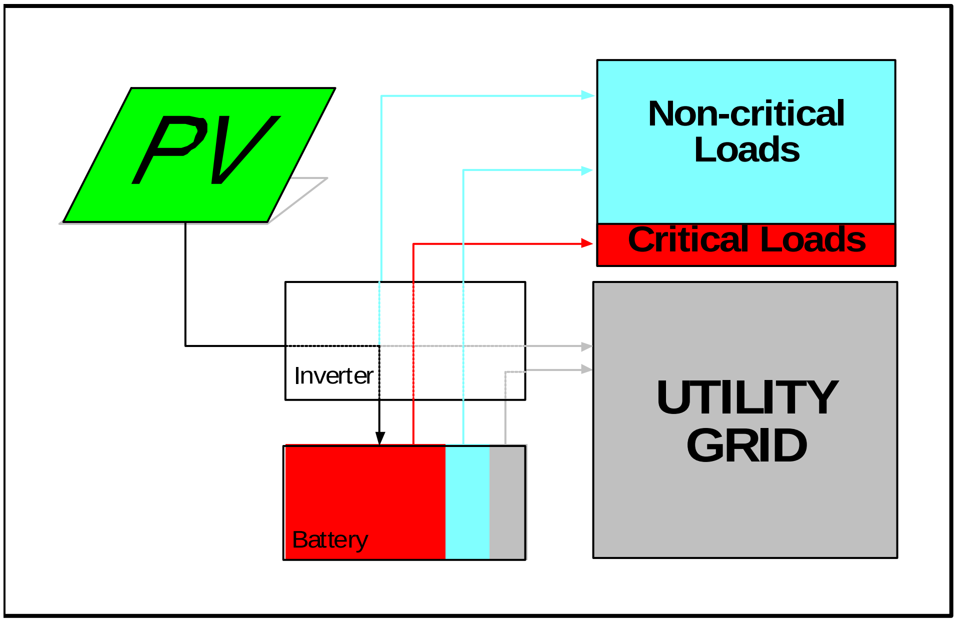

Figure 2. Customer-sited PV with battery storage.

Table 1. Potential benefits.

Benefit **Description**	**Who Benefits?**	**What Equipment is Required?**				
		PV	**Inverter**	**Batteries**	**Load Control**	**Utility Controls**
Utility Bill Savings	Customer	YES	YES	NO	NO	NO
Added Bill Savings Due to Demand Reduction	Customer	YES	YES	One or Both		NO
T&D and/or System-wide Demand Reduction Value	Utility	YES	YES	One or Both		YES
Outage Recovery Value	Customer	YES	YES	YES	NO	NO
Active Outage Prevention Value	Utility	YES	YES	One or Both		YES

Objective

The objective of this paper is to determine how the value of customer-owned PV can be increased with battery storage. The first part of the paper calculates the added value that a PV + storage combination provides to consumers. Both residential and commercial consumers are considered.

The second part of the paper discusses how utilities can take a more of an active role in PV in general and PV + storage in particular and thus increase the value of customer-owned PV systems.

Methodology: Determining Consumer Value

This section develops the methodology to calculate the added value that PV provides to consumers in terms of reduced storage capacity.

Annual Utility Bill

Calculating a consumer's annual electric utility bill requires economic and technical inputs. The economic input is the electric rate structure. This is the cost structure that is established by the utility. The technical input is the consumer's load. This is established by the consumer based on their usage patterns. The economic and technical inputs are combined to calculate the annual utility cost. Since consumers tend to view their consumption as a fixed amount,[1] call it *Load*, the annual cost can be stated mathematically as:

$$C_{Utility}\left(Load\right)$$

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[1] This analysis ignores the potential for energy efficiency, not because of its importance, but in order to simplify the problem. This assumption would be correct if the consumer has already implemented all of the cost-effective energy efficiency that is available to them.

Outage Cost

One limitation of this cost formulation is that it excludes the potential cost due to power outages and/or power shortages. That is, there are costs to most consumers if they lose part or all of their power. Call this the outage cost, C_{Outage}. If the consumer is an expected value decision maker, the expected outage cost equals $E\lfloor C_{Outage} \rfloor$, where E is the expected value. The total cost equals:

$$C_{Utility}(Load) + E\lfloor C_{Outage} \rfloor$$

The outage cost calculation requires economic and technical inputs. Unlike the utility bill cost calculation, however, the source of the required inputs is reversed. The consumer, rather than the utility, is the source of the economic input and the utility, rather than the consumer, is the source of the technical input. The consumer determines the economic cost of an outage given that it occurs and the utility has the best understanding of the probabilities of how often and when the outages occur.

Distributed Resources

This problem formulation is correct when the consumer's only option is to obtain power from the utility. Consumers, however, have other alternatives, including photovoltaics (PV) and storage. When presented with these alternatives, the consumer needs to decide how much storage, how much PV, and how much utility power to purchase. The goal for many consumers would be to purchase PV and storage systems of sizes such that the cost of the systems plus the cost of the utility bill and expected outage costs are minimized.

Assume that PV system size (S_{PV}) affects PV cost, the amount of power purchased from the utility, and the expected outage cost and that storage size ($S_{Storage}$) affects storage cost and the expected outage cost. The problem can be stated as the following cost minimization problem.

$$\underset{S_{PV},\, S_{Storage}}{\text{minimize}} \quad \overbrace{C_{PV}(S_{PV})}^{\text{Cost of PV}} + \overbrace{C_{Storage}(S_{Storage})}^{\text{Cost of Storage}} + \overbrace{C_{Utility}(Load, S_{PV})}^{\text{Cost of Utility Power}} + \overbrace{E\lfloor C_{Outagee}(S_{PV}, S_{Storage})\rfloor}^{\text{Expected Outage Cost}}$$

Problem Solution

The solution to the cost minimization problem includes the optimal PV size and the optimal storage size. The following data are required to determine the solution:

1. PV cost as a function of PV system size
2. Storage cost as a function of storage size
3. Cost of utility power as a function of PV system size
4. Outage cost
    a. Outage cost as a function of PV and storage size
    b. Outage probabilities (to calculate the expected value)

The first three data requirements are feasible to obtain.

1. PV system cost can be assumed to be linearly related to PV system size

2. Storage cost can be assumed to be linearly related to storage size
3. The cost of utility power, which depends upon the rate structure, customer load, and PV system size, can be calculated using a tool such as QuickQuotes.[2]

It is difficult, however, to obtain the fourth data requirement: outage cost and the associated outage probabilities. Consumers need to specify their outage cost (which is determined by a variety of factors, such as their load profile, when did the outage begin, how long did the outage last) and the utility needs to specify their outage probabilities. Few consumers, particularly residential ones, could quantify their outage costs. Likewise, it would be difficult to obtain information about the probability of outages at a particular location from the utility. This makes solving the optimization problem very difficult.

Constrained Optimization Problem

One way to overcome this issue is to convert the problem to a constrained optimization problem by dropping the expected outage cost calculation and adding a constraint. The constraint is that a specified critical load must always be satisfied for a given outage duration at all times during the year. That is,

$$\underset{S_{PV},\, S_{Storage}}{\text{minimize}} \quad \overbrace{C_{PV}\left(S_{PV}\right)}^{\text{Cost of PV}} + \overbrace{C_{Storage}\left(S_{Storage}\right)}^{\text{Cost of Storage}} + \overbrace{C_{Utility}\left(Load, S_{PV}\right)}^{\text{Cost of Utility Power}}$$

$$\text{s.t. Critial load be satisfied for H hours of outage}$$

Net Benefit of PV

Suppose that S_{PV}^{H} is the optimal PV system size and $S_{Storage}^{H\ w/\ PV}$ is the optimize storage size when the consumer wants H hours of outage protection. The solution to the cost minimization problem is:

$$\overbrace{C_{PV}\left(S_{PV}^{H}\right)}^{\text{Cost of PV}} + \overbrace{C_{Storage}\left(S_{Storage}^{H\ w/\ PV}\right)}^{\text{Cost of Storage w/ PV}} + \overbrace{C_{Utility}\left(Load, S_{PV}^{H}\right)}^{\text{Cost of Utility Power w/ PV}}$$

When PV is not an option, the solution equals the cost of storage plus the original utility bill:

$$\overbrace{C_{Storage}\left(S_{Storage}^{H\ w/o\ PV}\right)}^{\text{Cost of Storage w/o PV}} + \overbrace{C_{Utility}\left(Load, 0\right)}^{\text{Cost of Utility Power w/o PV}}$$

The net benefit due to PV equals the difference between the total cost without PV minus the total cost with PV. The difference between the two previous equations can be

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[2] QuickQuotes is one of the software tools that are powered by the Clean Power Estimator analysis engine and database. Papers and articles are available at www.clean-power.com that describe the Clean Power Estimator.

rearranged to show that the net benefit of the PV system equals the savings in utility bill due to the PV system (i.e., original utility bill minus the new utility bill) minus the PV system cost plus the savings in storage cost (i.e., storage cost without PV minus storage cost with PV).

$$\text{Net Benefit} = \underbrace{\left[\overbrace{C_{Utility}\left(Load, 0\right)}^{\text{Cost of Utility Power w/o PV}} - \overbrace{C_{Utility}\left(Load, S_{PV}^{H}\right)}^{\text{Cost of Utility Power w/ PV}} \right]}_{\text{Utility Bill Savings}} - \overbrace{C_{PV}\left(S_{PV}^{H}\right)}^{\text{Cost of PV}} + \underbrace{\left[\overbrace{C_{Storage}\left(S_{Storage}^{H\ w/o\ PV}\right)}^{\text{Cost of Storage w/o PV}} - \overbrace{C_{Storage}\left(S_{Storage}^{H\ w/\ PV}\right)}^{\text{Cost of Storage w/ PV}} \right]}_{\text{Storage Cost Savings}}$$

Methodology: Storage Value Analysis

QuickQuotes was designed to calculate the net benefit provided by PV (i.e., the utility bill savings minus the cost of PV). Since it did not calculate the additional storage cost savings attributable to PV, it needed to be modified to perform this calculation. This section describes how the calculation is performed and then implemented in QuickQuotes.

Critical Load

Providing all of a consumer's normal electricity requirements using storage is an unlikely scenario due to the excessive cost. Rather, in the event of a power outage, most consumers would be willing to reduce their consumption to a lower critical level. Furthermore, it is likely that this critical load differs by time of day. It is assumed that there is a base load that occurs during all hours of the day and a peak load that occurs between certain hours. These inputs are specified by the consumer.

Battery Cost

In order to perform the analysis, an assumption needs to be made about the cost of batteries. One needs to be careful at this point to maintain consistency in units. One cannot simply determine the cost of batteries based on their listed rating. This is because the rating of the battery is based on a given rate of discharge; the amount of kWh one can get out of a battery decreases as the rate increases. In addition, batteries typically cannot be completely dispatched without damaging them.

There are two ways to accommodate these effects when performing economic calculations. One option is to accept the battery cost as a given and then to adjust the amount of storage required. The other option is to accept the battery capacity as a given and to adjust the cost per kWh. The second option is taken in this analysis.

The effective storage component cost is calculated from the retail prices of a preassembled lead acid battery for renewable energy applications.[3] Table 2 presents the pricing and capacity for a variety of 12V batteries. Ampere-hour ratings are given by the manufacturer at the 20 hour discharge rate. These are converted to 10 hour rates assuming a 50% derating penalty. Cycle life expectancy is 2100 cycles to 80 percent depth of discharge, or 6000 cycles to 20 percent depth of discharge. For purposes of this analysis, the 2100 cycle rating is assumed to be sufficient, so the ratings are further reduced 20 percent to account for the depth of discharge. The results suggest that the costs range from $284/kWh to $339/kWh with an average cost of $308/kWh. It will be assumed that the battery cost is $300 per kWh for residential customers. In addition, it will be assumed that the battery cost is $100 per kWh for commercial customers due to their purchase of much larger battery capacities.

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[3] GBC HUP Solar Batteries. Prices taken from Real Goods website, http://www.realgoods.com.

Table 2. Battery cost.

	Capital Cost	w/ 8%Tax	Battery Capacity				Cost Per kWh
			Amp-Hours			kWh	
Discharge Rate			*20 hours*	*10 hours*	*10 hours*	*10 hours*	*10 hours*
Depth of Discharge			*100%*	*100%*	*80%*	*80%*	*80%*
	$1,695	*$1,831*	845	563	450	5.4	$339
	$1,810	*$1,955*	950	633	506	6.1	$322
	$1,955	*$2,111*	1055	703	562	6.7	$313
	$2,145	*$2,317*	1160	773	618	7.4	$312
	$2,255	*$2,435*	1270	847	678	8.1	$300
	$2,365	*$2,554*	1375	917	734	8.8	$290
	$2,650	*$2,862*	1482	988	790	9.5	$302
	$2,725	*$2,943*	1585	1057	846	10.1	$290
	$2,850	*$3,078*	1690	1127	902	10.8	$284
						Average	$306

QuickQuotes Modification

QuickQuotes (and the underlying Clean Power Estimator analysis engine and database) was modified to calculate the amount of storage that is required to satisfy the specified critical load with and without PV as a function of hours of outage protection. The program determines the amount of storage required to satisfy the critical load for every hour of the year for a given outage duration. Suppose that the consumer wants 8 hours of outage protection. The program calculates the required storage capacity in January from midnight to 8 AM, in January from 1 AM to 9 AM, etc. The month and hour in the year that has the highest storage requirement is the limiting factor; it determines the necessary storage capacity.

This calculation is made for storage with no PV and storage with PV. The difference between the two is the storage capacity savings as a result of having the PV system. The value equals the storage capacity savings times the storage cost with the value recurring each time the storage needs to be replaced.

Consumer Value: Residential Example

This section presents the results for a residential consumer in San Jose, CA using the modified QuickQuotes. This consumer has an annual utility bill of $1,200 and has determined that they have a critical load of 100 Watts during the night and 400 Watts during the day (8 AM to 5 PM) as shown in Figure 2. This critical load corresponds to 20 percent of the consumer's normal consumption.

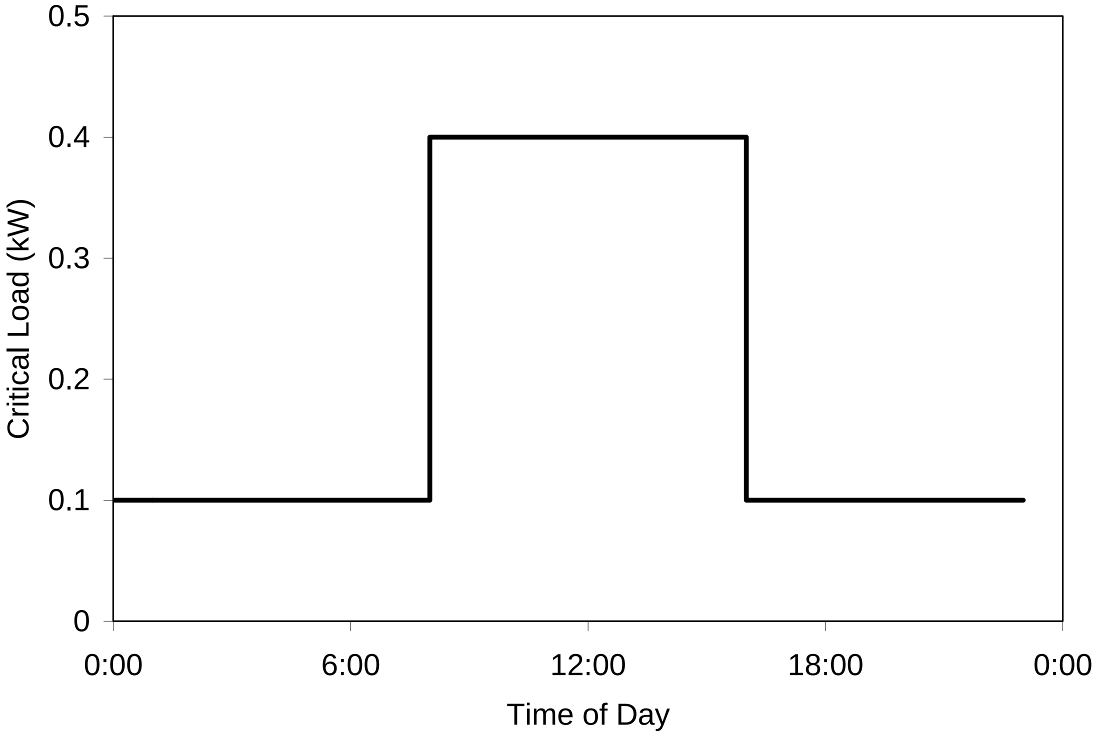

Figure 3. Critical Load

QuickQuotes was run to determine the amount of storage capacity required to satisfy the critical load for a range of outage durations. The top part of Figure 3 presents the results of the storage capacity versus outage duration for PV systems ranging in size from 0 kW to 3 kW. The bottom part of the figure presents the difference between storage capacity with and without PV. This difference is the storage capacity savings.

Assume that the consumer wants to be protected against power outages that last up to 8 hours. As shown in the top of Figure 4, the amount of storage required to protect against an 8 hour outage any time in the year without PV equals 3.2 kWh and the amount of storage required with PV is 1.2 kWh. This corresponds to 2 kWh of storage capacity savings. As shown in the bottom of Figure 4.

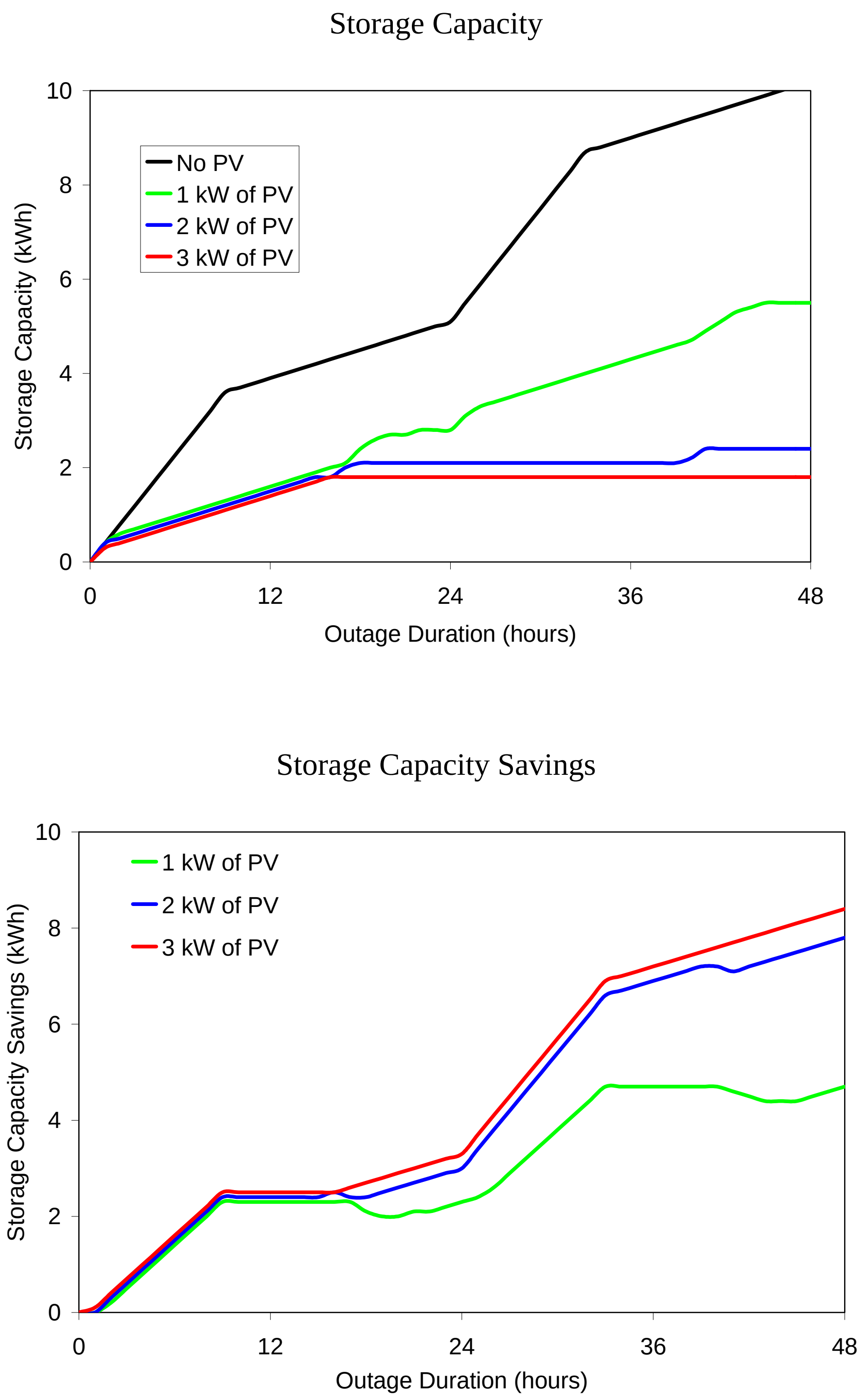

Figure 4. Storage capacity (and savings) versus outage duration for a peak critical load (0.1 kW base load with 0.4 kW peak load).

The capacity savings is combined with the storage cost and replacement frequency to determine the added value due to the PV system. It is assumed that storage costs $300 per kWh and needs to be replaced every 7 years. Table 3 presents the cash flow for 1 kW of PV with 8 hours of outage protection.[4] As can be seen in the table, there is a "Storage Cost Savings of about $600 that occurs every 7 years. The storage cost savings is calculated as follows. It is estimated that the consumer would have required 3.2 kWh of effective storage capacity without PV. With PV, they only require 1.2 kWh. The cost of storage without PV is $960 and the cost of storage with PV is $360. Thus, there is a savings of $600 due to the PV. QuickQuotes incorporates this savings that occurs every 7 years into the net present value (NPV) calculation. The result is that the NPV is increased from $1,926 without the storage value to $3,355 with the storage value.

Table 3. Cash flow for 1 kW PV with 8 hours of outage protection, $300/kWh storage.

Year	Capital Cost	Incentives	Electric Bill Savings	Loan	Storage Cost Savings	Tax Effect: Loan	Net Cash Flow
2004	($7,557)	$2,565	$0	$4,992	$594	$0	$594
2005	$0	$265	$400	($399)	$0	$111	$378
2006	$0	$0	$404	($399)	$0	$110	$116
2007	$0	$0	$408	($399)	$0	$109	$119
2008	$0	$0	$412	($399)	$0	$107	$121
2009	$0	$0	$417	($399)	$0	$106	$124
2010	$0	$0	$421	($399)	$0	$104	$127
2011	$0	$0	$425	($399)	$594	$103	$723
2012	$0	$0	$429	($399)	$0	$101	$132
2013	$0	$0	$434	($399)	$0	$99	$134
2014	$0	$0	$438	($399)	$0	$97	$136
2015	$0	$0	$442	($399)	$0	$95	$139
2016	$0	$0	$447	($399)	$0	$92	$141
2017	$0	$0	$451	($399)	$0	$90	$143
2018	$0	$0	$456	($399)	$594	$87	$738
2019	$0	$0	$460	($399)	$0	$84	$146
2020	$0	$0	$465	($399)	$0	$81	$147
2021	$0	$0	$469	($399)	$0	$78	$149
2022	$0	$0	$474	($399)	$0	$74	$150
2023	$0	$0	$479	($399)	$0	$70	$151
2024	$0	$0	$484	($399)	$0	$66	$151
2025	$0	$0	$488	($399)	$594	$62	$746
2026	$0	$0	$493	($399)	$0	$57	$152
2027	$0	$0	$498	($399)	$0	$52	$152
2028	$0	$0	$503	($399)	$0	$47	$151
2029	$0	$0	$508	($399)	$0	$41	$151
2030	$0	$0	$513	($399)	$0	$35	$149
2031	$0	$0	$519	($399)	$0	$28	$148
2032	$0	$0	$524	($399)	$594	$21	$740
2033	$0	$0	$529	($399)	$0	$13	$143
2034	$0	$0	$534	($399)	$0	$5	$140

This analysis was repeated for 1, 2, 3 and 4 kW PV systems with outage protections of 0, 2, 8, and 24 hours. The results are presented in Figure 5. They suggest that the NPV is

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[4] All of the other incentive and rate assumptions are as they existed on September 1, 2004 in the Clean Power Estimator database. It is assumed that the consumer begins on an E-1 rate and switches to a time-of-use net metered E-7 rate.

almost doubled for a consumer who desires 8 hours of outage protection and has a peak day time critical load.

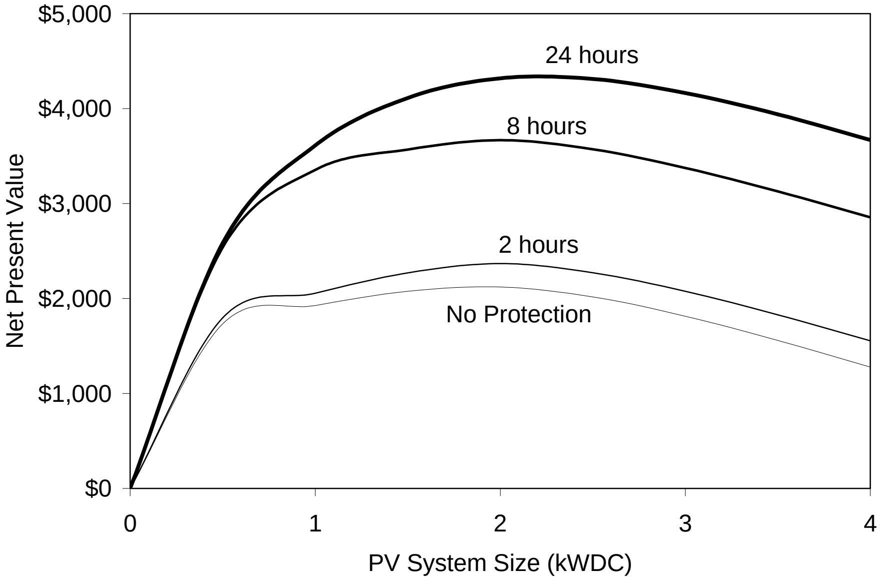

Figure 5. PV system size optimization.

Analysis Caveats

There are two important caveats that need to be made with regard to this analysis. First, PV output in QuickQuotes is based on a typical 24-hour day for each month of the year. As a result, there will be days during each month when PV output is higher or lower than the average, particularly during months with inclement weather. This could increase the amount of storage required to obtain a given level of outage protection under all conditions and thus reduce the storage capacity savings.

Second, the results are sensitive to the shape of the critical load. In particular, a consumer that has a constant critical load will require more storage than a consumer with a daytime peak critical load. For example, Figure 6 presents the storage capacity savings versus outage duration for a constant 0.2 kW critical load rather than the peak critical load used above. The figure suggests that PV only begins to provide added value above 14 hours of outage duration with a constant load. The results from the previous graph are included for comparison purposes.

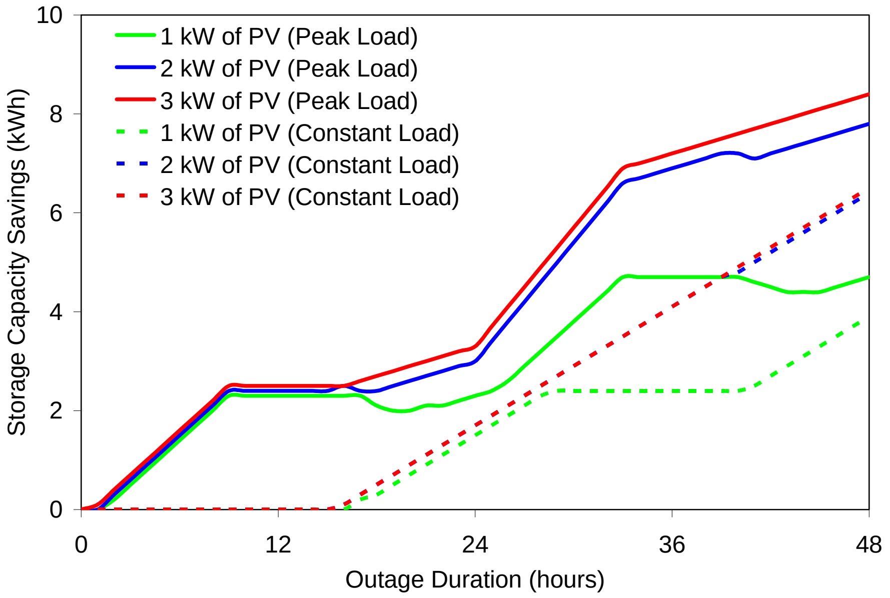

Figure 6. Storage capacity savings versus outage duration for a constant critical load.

Consumer Value: Commercial Customer Example

The previous section gave an example of the potential benefit from the perspective of a residential consumer. This section provides an example for a commercial consumer.

The previous section emphasized that PV is beneficial to consumers because they can obtain the same amount of outage protection with less storage capacity. This is also true for commercial customers.

One of the differences between residential and commercial customers is they have different rate structures. In particular, utilities tend to offer commercial customers:

- More rate structures from which they can choose
- Rate structures that include demand charges
- The choice between firm and non-firm service rate structures

As a result, an additional benefit that may be available to commercial customers is the value of switching from a firm rate structure to a non-firm rate structure. The benefit of this is that all of the customer’s power would be billed under the lower cost rate structure.

For example, PG&E has medium and large demand general service rates (E-19 and E-20 rate structures) that offer commercial customers the option of firm or non-firm service. The demand charges are much lower on a non-firm rate (there is also some reduction in the energy charges).

To illustrate the potential value, consider the example of a commercial customer in San Jose, CA that has a $300,000 annual utility bill (375 kW peak demand), 2% escalation and is currently on an E-19S firm service rate. Assume also that the customer has a critical base load of 50 kW and a critical peak load of 100 kW from 8 AM to 5 PM (this corresponds to 24% of annual consumption).

The customer is considering the purchase of a 200 kW_{DC} system at a cost of $\$6/W_{DC}$ using a payment method of cash. QuickQuotes was used to calculate the value of the PV system to the customer. As shown in Table 3, the PV system by itself has an NPV of ($5K) suggesting that it is not quite optimal to invest.

Assume that the customer requires 6 hours of outage protection at a cost of $100 per kWh that needs to be replaced every 10 years. This cost is assumed to be one-third of what a residential customer would pay because the commercial customer is buying a much larger quantity (hundreds of kWh versus a few kWh for consumers). The life is assumed to be longer (10 years versus 7 years) because the batteries are better maintained.

QuickQuotes determined that the customer requires 600 kWh of storage without PV and 400 kWh with PV. Table 3 indicates that the cost savings due to a reduction in storage capacity increases the NPV to $30,000.

In order to quantify the load management value that storage may bring to a commercial customer, let's assume that the customer switches to a non-firm rate structure because they have a backup storage system. In order to qualify for non-firm E-19 service,[5] a customer may be requested to curtail, on a pre-emergency basis, up to five times per year. Each pre-emergency curtailment will last no more than five hours. Customers will be given at least 30 minutes notice before each curtailment. PG&E will request at least six pre-emergency curtailments during any rolling three-year period.

The customer assumes that it can reduce to its critical load if needed. However, they believe that it is most likely that the curtailment will occur during the daytime in the summer when the PV output is most prevalent. As a result, rather than having to reduce to their critical load, they may still be able to meet half of their daytime power needs. They recognize, however, that they will not have outage protection for these few times in the year if they are curtailed and there is an outage after their storage capacity is exhausted.

The annual utility bill savings with PV is increased from about $35K on a firm rate to about $50K on a non-firm rate. This increases the NPV to almost $200K as shown in Table 3.[6]

Table 3. Value to commercial customer.

	NPV	IRR
200 kW_{DC} of PV	-$5K	6.9%
Add outage protection value	$30K	7.8%
Add outage protection value & non-firm rate switch	$195K	11.5%

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[5] http://www.pge.com/tariffs/pdf/E-19.pdf

[6] Switching to a non-firm rate without any PV reduces the $300K utility bill by 7 percent every year.

Utility Value

The first part of this paper presented a method to determine the added storage value that PV provides from the customer's perspective. This section describes the value of customer-owned battery systems from the utility's perspective. It begins with a basic discussion of distributed resources and how utilities can take a passive or an active role with PV. It then focuses on how customer-owned storage can be used for the utilities' benefit.

Background

The value of distributed resources (DR) depend upon where, when, and how much power they produce. Where the power is produced depends upon the resource's location in the utility network. When and how much power is produced depends upon installation and mode of operation.

DR can be categorized in a variety of ways. When categorized in terms of ownership, systems are utility-owned or customer-owned. When categorized in terms of mode of operation, systems are dispatchable or non-dispatachable.

The ownership categorization is important in terms of value because decision makers maximize economic benefit from their perspective by making decisions that include: (a) where systems are located, (b) how systems are installed, and (c) how systems are operated. In the absence of physically moving a DR, the first two decisions are only made once. The third decision (how to operate the DR) may be made continually over the life of the system.

The dispatchability categorization is important because there is no decision on how the DR is operated when it is a non-dispatchable technology: it operates whenever the fuel source (i.e., the sun in the case of PV) is available.

One criticism that utility personnel tend make about PV as a DR is the lack of assurance that the output will be available when the T&D system needs it the most. While this is a valid concern, the non-dispatchability of the PV can actually be viewed as an asset because the mode of operation for a non-dispatchable DR does not depends upon who owns the system. That is, there are no control decisions to be made with non-dispatchable DR because they are operated when the fuel (i.e., the sun) is available.

If the utility offers the financial incentives so that the correct one-time decisions are made (i.e., systems are installed in the optimal location and orientation), the utility does not need to give consideration to the issue of how the system is operated because the technology is non-dispatchable.

As a result, PV is one of the few commercially available technologies that utilities should be indifferent between their owning or the customer owning because *the value of PV to* *the utility is independent of the ownership (utility-owned or customer-owned) once the system has been installed.*[7]

A potential criticism that remains from the utilities' perspective is the technical issue that PV may not be available due to a lack of solar resource when the T&D system is constrained.

One way to overcome this criticism is to bundle PV with a dispatchable resource such as a load management technology or a battery. Because of the natural correlation that often exists between PV output and load requirements, the amount of dispatchable "add-on" resource does not need to be considerable.

Active Utility Participation

Rather than being a passive recipient of the benefits from customer-owned PV systems, the utility could take an active role and interact with the PV systems to maximize the value to the utility. Consider some ways in which the utility could benefit from an active role.

PV System Location

Most utilities have transmission and distribution (T&D) system constraints within their overall network. A passive approach is to allow the PV systems to be installed anywhere in the system without any guidance from the utility. An active approach is for utilities to use financial incentives to influence which customers install PV systems so that they are located on capacity-constrained T&D systems. Since many system constraints are driven by high daytime loads and there is often a good correlation between PV system output, locating multiple PV systems on a particular T&D system has the potential to defer a T&D upgrade ([2], [3], [4], [7], and [8]).

PV System Orientation

The amount and timing of PV system energy production depends upon the system installation and orientation. In the absence of any shading issues, PV systems typically produce the most energy when oriented facing south and tilted at about the number of degrees of the latitude. The utility, however, may desire to have the system facing in the southwest or west direction so that it obtains a greater peak load reduction later in the day. The better match to the peak load would occur at the expense of a reduction in the amount of energy produced ([1], [7], and [8])

While some utilities have time-of-use rate structures that slightly encourage PV systems to be installed in a west direction, most utilities are very passive in this area. The utility could take a more active approach and provide a stronger incentive through rate structure design or an initial financial incentive.

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[7] System location and orientation can be controlled by the utility by having them offer customer's a financial incentive.

PV System Operation

A concern that is expressed by some utility distribution planning engineers when considering PV as an alternative to a T&D upgrade is that, while PV system output may be highly correlated with T&D system load, the correlation may not be perfect. As a result, in order to obtain the same sort of confidence that they have in a T&D system upgrade, these planners require detailed studies that examine PV system output and T&D system load over a number of years. Even after the studies are performed, some planners still have more confidence in the wire than the PV system alternative.

An active approach is for the utility to combine PV with a utility-dispatchable load reduction device. While the load reduction device might not be economically feasible alone because it would have to be dispatched too often, it may be feasible in combination with a PV system. This could mitigate the distribution engineer's concern that the T&D system upgrade cannot be prevented because they do not have enough assurance that the PV will be available when the system is constrained.

Emergency Outage Prevention Description

Another way that utilities can increase the value of PV to themselves by taking an active approach is in the prevention of system-wide outages. First, they should encourage customers to install PV systems in weak points on the system. Perez and Collins have examined this approach and determined that a relatively small amount of PV that was strategically located had the potential to prevent the massive outage on the East Coast in August 2003.[8]

Second, utilities should consider obtaining the right to dispatch customer-owned battery backup systems in the event of system emergencies. Caution needs to be exercised, however, when selecting the type of emergencies that customer-owned storage is used to solve. Consumers value storage because of its outage protection. Storage that is fully dispatched will be unavailable for emergency outage protection until it is recharged. If the utility dispatches the storage to solve a problem that lasts for several hours, the consumer might lose their outage protection.

Thus, customer-owned emergency backup batteries should not be dispatched to solve problems that occur over an extended duration of time. Rather, they should be used for their quick start, high output capabilities for a short duration of time, such as to avoid a system wide outage. This would consume very little of the storage's energy capability, thus providing the utility with enough time to take corrective action to avoid a power outage and still leaving the consumer with most of the outage protection capability.

This option is desirable to consumers because one of two outcomes will occur: (1) the dispatch avoids an outage and the consumer's backup storage is not needed; (2) the dispatch does not avoid an outage but the battery systems have most of their energy left and consumers use them to meet their critical loads.

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[8] R. Perez and B. Collins, Solar Energy Security: Could Dispersed PV Generation Have Made a Difference in the Massive North American Blackout? reFOCUS July/August 2004.

Emergency Outage Prevention Value

The value of dispatching customer-owned batteries depends on how much power can be produced and the value of that power. The amount of power that can be produced depends upon maximum power output of the storage, the maximum rating of the inverter, and the amount of output from the PV system. It equals the lesser of the maximum inverter rating minus PV system output and the maximum output of the storage. That is, the power production is limited by both the rating of the battery system and the unused inverter capacity.

Determining the economic value of the power is a much more difficult issue. Utilities do not typically have a price they are willing to pay customers for instant capability to respond to such situations for a short duration of time. While there are some possible sources, such as the California Independent System Operator (CAISO), the products offered there are different than what is being considered here. For example, the CAISO procures ancillary services that include *regulation*, *spinning reserve*, *non-spinning reserve* and *replacement reserves* in its Day-Ahead and Hour-Ahead markets and *voltage support* and *black start* on a long-term basis through the Reliability Must Run (RMR) contracts. These products differ from what is discussed here.

The storage service discussed here is an option that could be very attractive to utilities. The utility could dispatch the storage under emergency situations for only a few minutes and would only need to represent a fraction of the total system load. The utility could then make arrangements to deal with the emergency in other ways. It could be used to provide them enough time to deal with problems such as a potential system wide outage or the loss of a major transmission system (or even a distribution system).

Conclusions

Consumers in the U.S. have become accustomed to a highly reliable source of electricity. In the process, they have become vulnerable to unexpected power outages. As a result, major outages similar to the one that occurred on August 14, 2003 on the East Coast are very costly and disruptive. Rather than being an isolated incident, however, a number of experts believe that we should expect that these unexpected outages will continue to occur. This suggests that consumers need to protect themselves against such outages.

The paper examined how storage can be profitably combined with customer-owned PV systems. Results indicate that there is value to both consumers and the utility. There is value to consumers in two ways. First, both residential and commercial customers can obtain outage protection with less storage capacity when combined with PV, thus resulting in a capital cost savings; the amount of savings depends upon the customer's critical load and the amount of PV. Second, commercial customers may achieve additional utility bill savings by moving from firm to non-firm rate structures by providing for their own power needs if and when their load is curtailed.

There is also value to utilities. They may be able to dispatch customer-owned batteries for a short duration of time (a few minutes) in the event of system emergencies. This may prevent a catastrophic outage while using only a fraction of the batteries' capacity. This would allow the battery systems to continue to provide consumers with outage protection in the event the outage still occurs.

All value elements could be included in a standard PV+storage configuration, where storage portions would be apportioned to meet all value enhancing functions.

Future Work

There are a number of areas of future work. This section describes some of the areas.

Added Energy Production

This research found that critical loads may be satisfied with less storage capacity with PV than without PV, thus resulting in a storage capital cost savings. Another benefit is that consumers may have more energy production with PV during certain times of the day. The storage system by itself will only deliver a certain amount of energy. Systems that include PV, however, will produce more energy than what is in the storage alone. A method needs to be developed that accounts for this benefit.

PV Output Uncertainty

A primary finding of this work is that PV provides value by reducing the amount of storage capacity needed to meet critical loads when there is a strong peak in the daytime critical load. The QuickQuotes PV output model is based on a typical day for each month of the year. As a result, the storage is sized based on the typical day output rather than the worst day output. One could assume that some days will have negligible PV output. This would lead to the result that there is less storage capacity savings with PV. An alternative solution is to account for PV output uncertainty and then to allow the customer to specify the percent of time that they want to be able to meet their critical load in the event of an outage (some number less than 100 percent). The analysis could be performed under this situation to determine the storage capacity savings.

Battery Characteristics

This research made a number of assumptions about the technical and economic characteristics of the battery. These assumptions need to be further evaluated and better modeled in order to improve the analysis.

- Battery life. The paper assumed that batteries need to be replaced every 7 years for residential consumers. In reality, battery life could be shorter or longer and it is partially related to the dispatch patterns.
- Effective battery capacity. The paper assumed that battery capacity is reduced by a fixed percent because the batteries are discharged at a faster rate than what is specified for the battery capacity. In reality, this rate will actually vary based on the dispatch rate at any given time.
- Battery cost. The paper assumed that the only cost of a storage system is the batteries. In reality, there is potentially an additional cost savings that the analysis did not account for because the cost of the power conditioning and other equipment that would have been required for the storage system is already provided by the PV system.

Rate Switch Feasibility

Results suggested that there is an economic benefit for commercial customers who add storage to their PV system because they can switch from a firm to a non-firm rate structure. The feasibility of this concept needs to be explored. In particular, it needs to be determined if customers are willing to switch rates. This may be accomplished by using an actual customer as a case study.

Utility Control

Allowing utilities to control a customer's battery resource is a unique, but not completely novel, concept. For example, a precedent exist is utility load control of devices such as electric water heaters. Several steps are required to flesh out this concept. First, a utility needs to be used as a case study to determine how much they would be willing to pay for such a service. Second, attention needs to be given to the technical implementation of this to determine if it is as simple as controlling electric water heaters or requires something more complex.

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