Microgrid Dispatch for Macrogrid Peak-Demand Mitigation

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ABSTRACT

For large utility customers, microgrid solutions – the installation of distributed generation and other energy resources, as well as the ability to seamlessly connect and disconnect from the grid—have emerged as a promising alternative to traditional macrogrid electricity, providing opportunities to lower utility bills by avoiding expensive on-peak rates from time-of-use (TOU) tariffs while enhancing the reliability of on-site electricity. The benefits of microgrids are however a two-way street. By not only responding to tariff price signals, but also through strategic dispatch, customer-operated microgrids can potentially reduce the demand peaks throughout distribution networks, even when customer and utility peaks are non-coincident. Reliably flattened demand profiles from targeted microgrid dispatch are potentially of great value to utilities, allowing the expansion of substation infrastructure to be postponed or avoided altogether.

A project to demonstrate this concept is currently underway at Santa Rita Jail, a large microgrid-enabled facility with a myriad of on-site distributed energy resources (DER) located in Dublin, CA. The facility load and resources will be assessed to determine whether the peak demand on the substation feeder can be reduced by 10% throughout the year. Through multi-objective optimization, using the DER-CAM platform, dispatch schedules have been generated to minimize both, distribution grid peaks and customer charges incurred under the tariff, simultaneously. Furthermore, feeder-constrained and customer-optimal solutions are compared to quantify cost differences and set the groundwork for incentivizing feeder peak reducing behavior in the future. It is the intention of this paper to demonstrate that with appropriate partnerships, tools and incentives, utilities can begin to view large customers as an asset to managing demand peaks.

Introduction

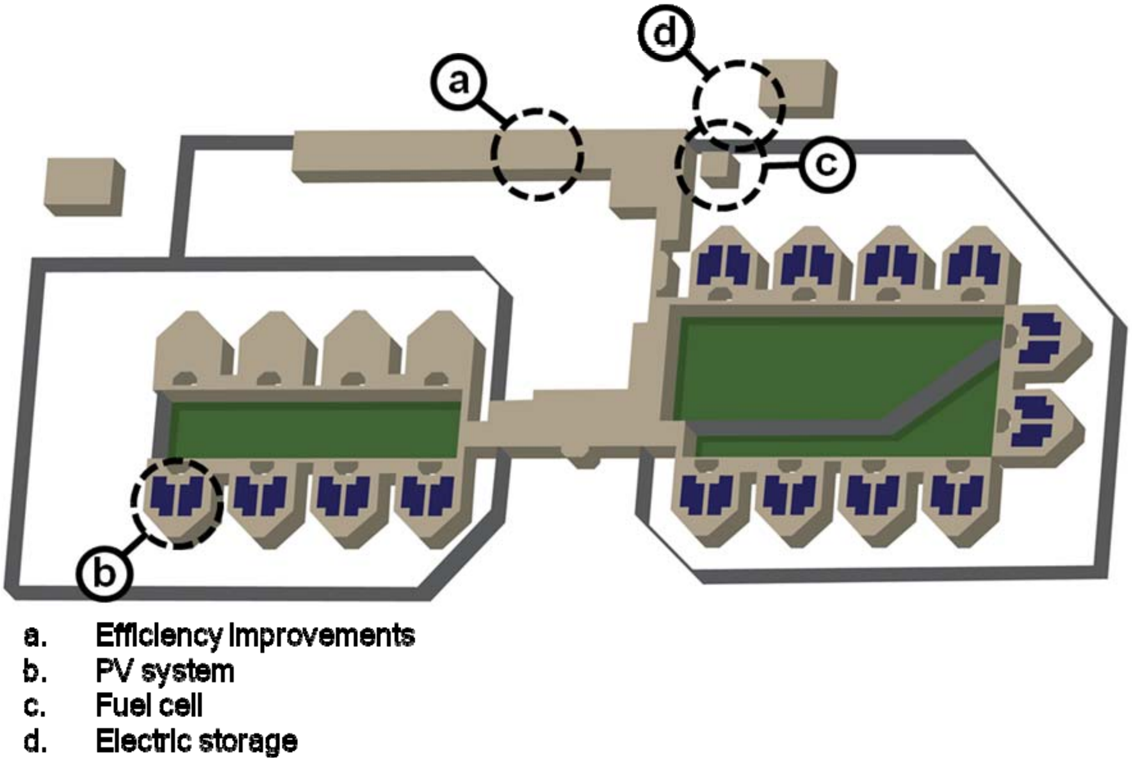
Similar to load-shifting for demand response, this investigation will determine to what extent electric storage at a large California facility can be used to reduce peaks in the electricity distribution network. However, rather than responding to signals from independent services operators (ISO), dispatch decisions are made in response to conditions on the local utility feeder. This case study presents a general overview of the facility, including its on-site energy resources and their respective impact on the goal of feeder peak reduction. Additionally, conditions of the feeder are diagnosed for a key summer month to determine when peak mitigation is necessary. In assessing historic feeder and facility data, this study presents an upper-bound potential for this reduction strategy. Ultimately, it will be financial incentives that determine whether this strategy will ever be undertaken by real-world customers. Therefore, analysis of the utility tariff, with particular attention paid to power demand charges, is performed to determine compensation and other tariff conditions necessary to encourage customer participation in feeder peak reduction.

Santa Rita Jail Overview

Santa Rita Jail (SRJ) is a 4.500 inmate facility located in Dublin, CA, near the San Francisco Bay area. Its current peak electricity demand exceeds 2.5 MW. The site has undergone a number of efficiency improvements and DER installations over the past decade in an effort to improve power reliability and reduce utility bills incurred under a TOU electricity tariff. These energy improvements—along with date completed, and peak electricity savings or generation capacity - include:

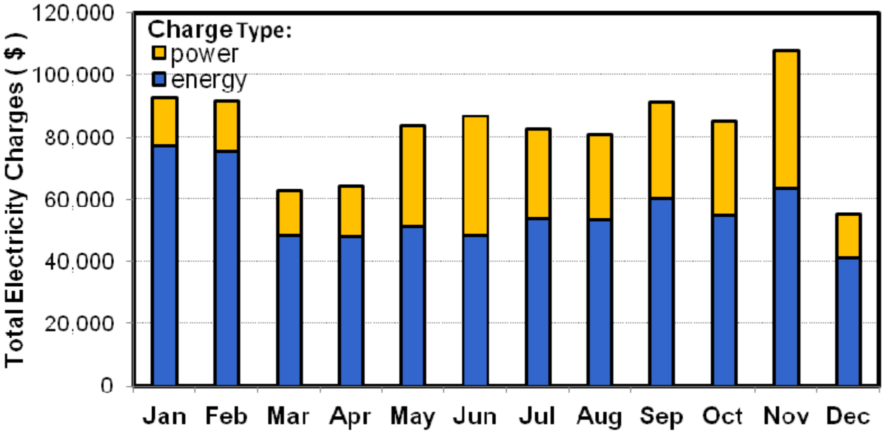
- chiller replacement (2001) - 423 kW reduction
- lighting retrofits (2009, 2010) - 442 kW reduction
- freezer upgrade (2010) - 71 kW reduction
- rooftop PV arrays, (2002) - 1.2 MW rated generation
- fuel cell with heat recovery (2006) - 1 MW electricity generation

Figure 1. Schematic Illustration of Santa Rita Jail Facility with DER Additions



A schematic illustration of SRJ is present in Figure 1. Efficiency measures (a) produce peak demand savings of approximately 900 kW. The PV arrays (b), while originally rated at 1.2 MW, have historically only produced a peak output of 700 kW (Dierckxsens 2009). The molten carbonate fuel cell (c) is meant to provide 1 MW of base-load electricity generation, with heat recovery used for hot water preheating also reducing natural gas demand. Each of these measures effectively produces a consistent reduction to demand on the feeder. The latest DER addition to SRJ is electric storage, in the form of a lithium-iron phosphate battery (d). The installed battery has an energy capacity of 4 MWh and a power capacity of 2 MW. The presence of distributed generation and storage technologies provide SRJ with microgrid functionality, allowing it to operate in island mode, separated from the grid (Marnay 2011a). Such equipment also allows SRJ to assist the utility in peak reduction or other ancillary services. The peak reduction potential in this investigation will focus solely on reductions from electric storage dispatch.

Figure 2. Composition of 2009 SRJ Electricity Bills



DER-CAM Optimization

Managing such a diverse selection of DER in a cost-efficient manner can be a challenge, especially considering the TOU tariff, which levies high fees for both energy and power demands during on-peak hours. The structure of the tariff under which SRJ purchases electricity is outlined in Table 1. Given the differences in rates between on-peak and off-peak periods, this tariff structure creates significant savings potential for electric storage. By purchasing electricity during off-peak hours and then discharging to offset electricity purchases during peak hours, the most expensive rates can be avoided. However, achieving this in reality can prove difficult. Figure 2 shows the composition of 2009 electricity bills at SRJ. Note that power demand charges comprise a significant portion of the bill each month—as much as 44%. These demand charges are set by the highest 15 minute average power demand in each period (off-peak, mid-peak, and on-peak). Therefore, low power demands must be maintained throughout the entire month in order to realize the full savings.

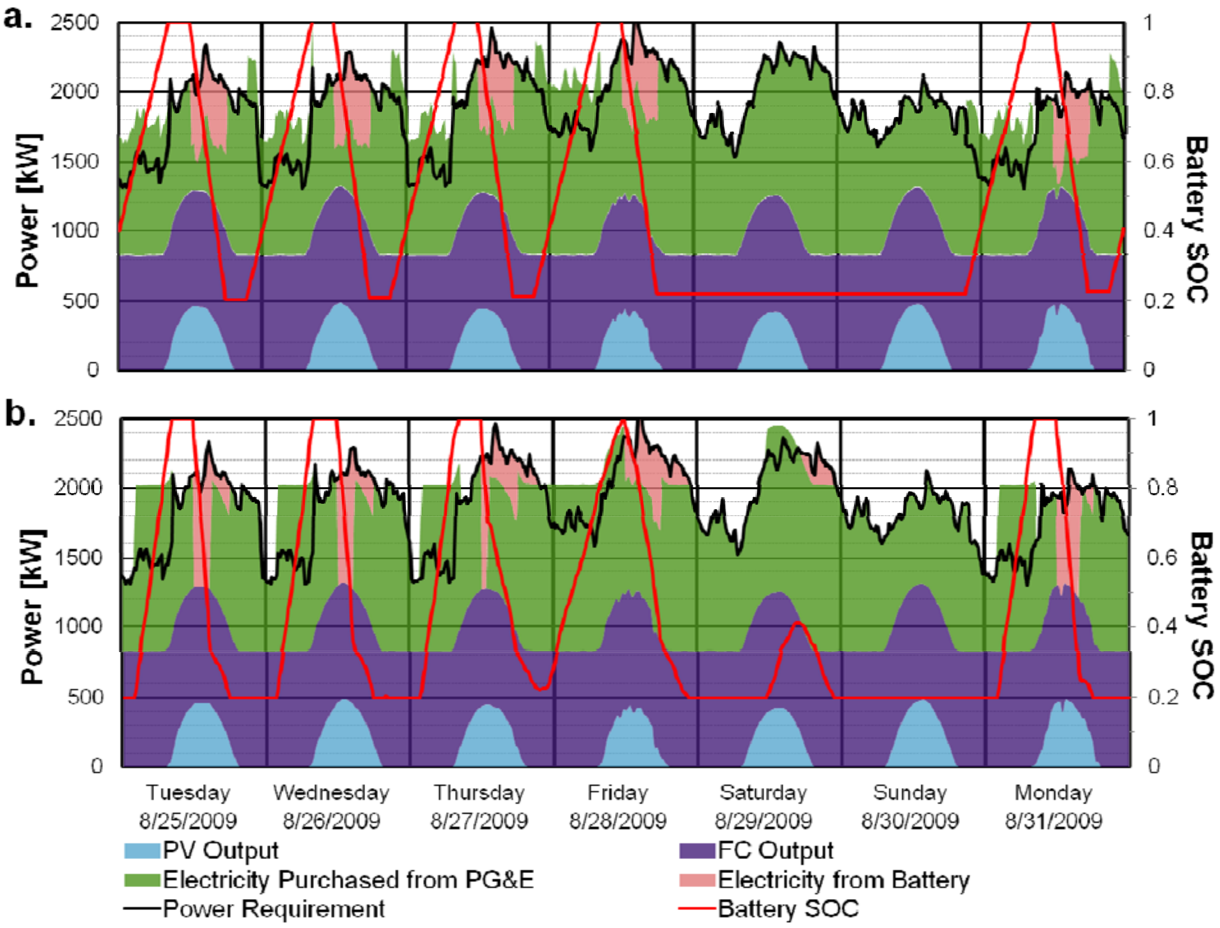
Table 1. Time of Use Electricity Tariff at SRJ

Period		Power [$/kW]	Energy [$/kWh]	Duration
Summer May-Oct	on-peak	11.04	0.14040	12:00-18:00, M-F
	mid-peak	2.59	0.09807	8:30-12:00, 18:00-21:30, M-F
	off-peak	0.00	0.07992	21:30-8:30, M-F; Weekends
	monthly max	7.45	-	
Winter Nov-Apr	mid-peak	0.82	0.08585	8:30-21:30, M-F
	off-peak	0.00	0.07664	21:30-8:30, M-F; Weekends
	monthly max	7.45	-	

Source: PG&E E-20 Industrial Tariff (PG&E 2012)

The *Distributed Energy Resources Customer Adoption Model* (DER-CAM) is an LBNL developed optimization platform that can help facilities like SRJ maximize savings from on-site DER equipment (Marnay 2011b, Stadler 2008, 2009). By utilizing forecasts of weather, loads and utility conditions, DER-CAM is able to generate cost-optimal schedules of dispatchable equipment, including charging and discharging of electric storage. The actual value of this optimal schedule will depend, of course, on the robustness of the forecasters, particularly for facility load. Forecasters are created through regression analysis of loads and pertinent drivers, most importantly temperature. Further development of DER-CAM includes stochastic optimization and considers uncertainty in loads and availability of some DER equipment. For the analysis present in this paper, however, insufficient data of the load on the utility feeder precluded the construction of all necessary forecasters. Consequently, historical data is utilized, which assumes perfect knowledge of future loads. This analysis therefore represents an upper-bound savings potential for electric storage scheduling.

Figure 3. Simple (a) and Cost-optimized (b) Electric Storage Schedules

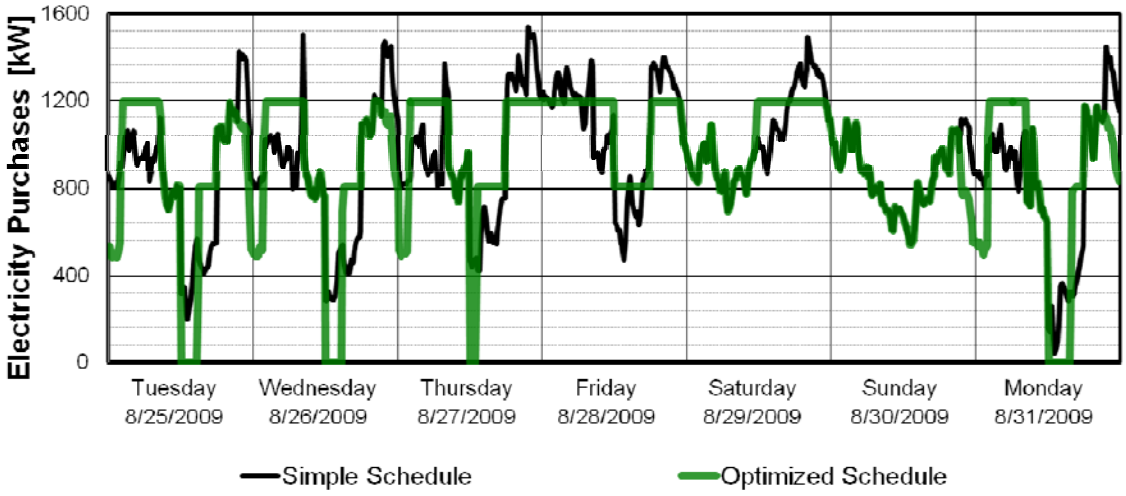


To illustrate the value of DER-CAM, two battery scheduling scenarios are applied to a month of SRJ load data (August 2009). The first is a very simple charging/discharging schedule. During off-peak hours (21:30-8:30) the battery is charged at a constant rate of 291 kW, such that the battery will be full at the end of this period. The minimum state of charge (SOC) of the battery is fixed at 0.2 for both scenarios and represents the starting point for charging. The SOC of the battery is maintained during mid-peak period, and then it is discharged at a fixed rate of 533 kW during on-peak hours (12:00-18:00). For this schedule, the battery is not cycled during weekends, which have no on-peak periods. Such a schedule is easy to implement and can be executed independent of weather and load conditions. It represents a baseline value of electric storage at SRJ. The second scenario utilizes DER-CAM optimized schedules for charging and discharging. Schedules for the last week of the month investigated (August 25-31) are also shown in Figure 3. The resulting power and energy charges for both scenarios are shown in Table 2. These values are determined simply by imposing the tariff rates to the electricity purchases of each scenario. In this specific case, DER-CAM is capable of increasing the value of electric storage by over $4,800 or approximately 19% compared to the simple case, with the additional savings coming exclusively from a reduction of power demand charges. Compared to the simple schedule (a), the DER-CAM optimized schedule (b) is clearly more effective at maintaining flat power demands across each TOU period. While the simple schedule offsets on-peak energy purchases, it cannot eliminate fluctuations in power demands, and ultimately, it is the highest observed power demand that sets the demand charge for the entire month, a fact illustrated by Figure 4, which shows a comparison of purchased electricity for each scenario.

Table 2. August Electricity Bill by Storage Schedule

Charge Type	No Storage	Simple Schedule	DER-CAM Optimized
Energy	$69,303	$54,487	$54,662
Power	$36,251	$25,915	$20,928
Total	$105,554	$80,401	$75,590

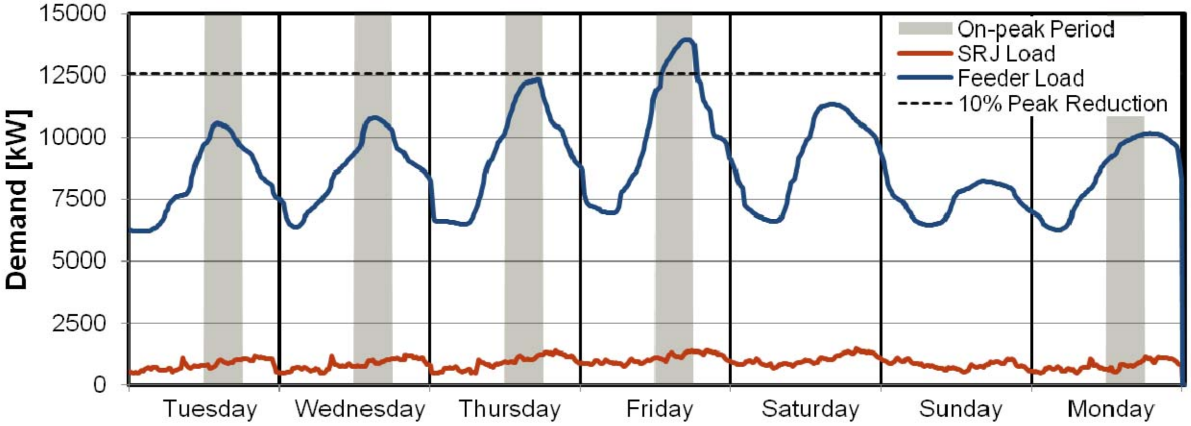
Figure 4. Electricity Purchase Profile for Simple and Cost-optimized Schedules



Utility Feeder Conditions

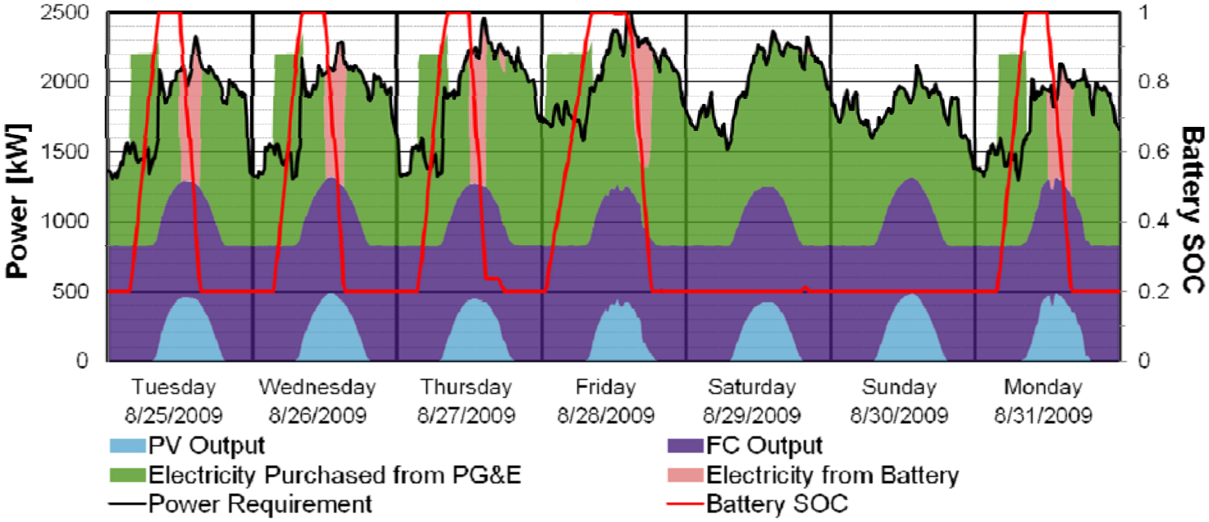
There is value to electric storage beyond bill reduction. Strategic scheduling can also be applied to reduce demand peaks in utility distribution systems. Analysis of SRJ's ability to mitigate these feeder peaks will focus on the week of August 25-31, 2009. During this week, the feeder experienced a summer peak demand value of 13.96 MW for the year. It is assumed that if electric storage at SRJ is capable of reducing the peak demand in this extreme case, it will likely also be able to reduce more moderate demand values during other times throughout the year. Because utility feeder peaks will not always be perfectly coincident with facility-optimal times for electric storage dispatch, there is bound to be some loss in value of electric storage from the facility's prospective if a feeder peak-mitigation strategy is employed. The weekly demand profile for the feeder, as well as the portion of that demand attributable to SRJ is shown in Figure 5.

Figure 5. Summer Peak Load Profiles for Utility Feeder and SRJ



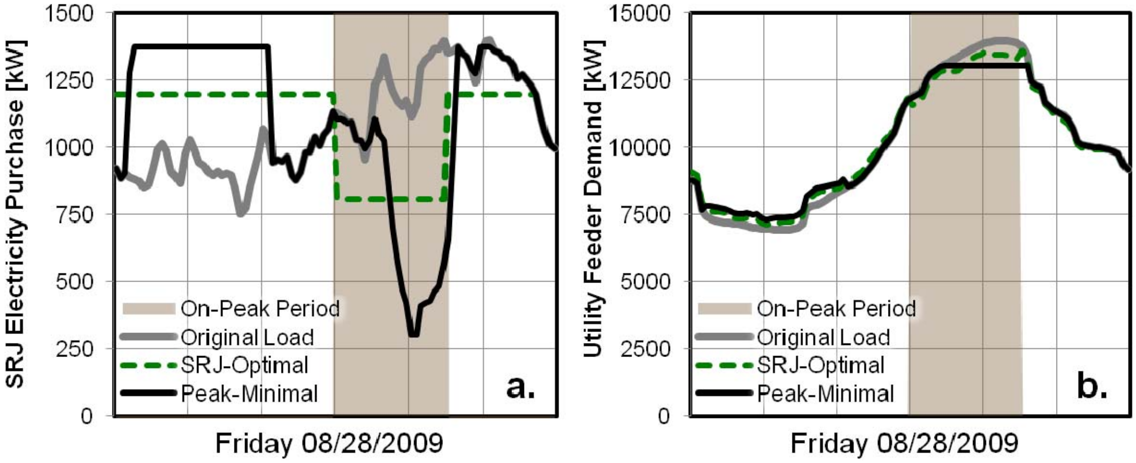
Looking closer at the maximum peak day (Friday, August 28) it is apparent that the period in which the feeder demand exceeds 90% of its peak value—the time where strategic dispatch would be necessary—is not entirely coincident with the on-peak period—as defined by the TOU tariff. While they are largely coincident, the slight discrepancy can produce significant increase in on-peak demand charges. Recall that the on-peak power rate is 4.24 times higher than the mid-peak rate, and monthly demand charges are set in single 15 minute periods. So by dispatching the battery during mid-peak periods for peak mitigation, SRJ reduces it potential to reduce on-peak purchases, and thus incurs higher electricity costs. It is also important to note that because on-site generation has so effectively reduced electricity purchased from the grid, SRJ only accounts for approximately 10% of demand on the feeder at its peak. This fact limits what SRJ is able to accomplish without having to export electricity back into the grid, which may further complicate the economics of this strategy. To determine the feeder reduction schedule, a multi-objective optimization is performed using DER-CAM, which first dispatches the battery to minimize the feeder peak, then generates the remainder of the charging-discharging scheduled to minimize utility charges incurred under the tariff. The results of this feeder-peak-minimal optimization are presented in Figure 6.

Figure 6. Peak-Minimal Electric Storage Schedule



There are two important implications to consider from this schedule. One, how will it affect electricity purchases at SRJ and therefore utility charges, and two, how effectively does it reduce the peak on the feeder? To explore this in more detail, Figure 7 shows SRJ electricity purchases (a) for the original no-storage case, the SRJ optimal case, and the feeder peak-minimal case for the critical day (Friday 8/28). The figure also shows the feeder demand profile (b) for each scenario on the right.

Figure 7. Electricity Purchases and Feeder Load for Cost-optimal and Peak-minimal Schedules—Peak Day Only



As these figures make apparent, the SRJ-cost-optimal schedule is very effective at maintaining flat power demand across the entire day, and particularly effective at lowering that power demand during the on-peak period. It does not, however, produce a significant reduction to the feeder peak. The effective peak in this case is only 2.7% lower than the original load case. Conversely, the peak-minimal case produces a flattened feeder demand profile with a peak saving of 6.5%. It is the energy capacity of the electric storage (4 MWh) that constrains the savings potential. Realizing this level of feeder-peak savings, however, prevents SRJ from using its electric storage to maintain a low, flat power demand during on-peak hours, as shown in Figure 6a. Note that, while the peak-minimal case does offset a large portion of on-peak electricity, the power demand in this period fluctuates from 1,100 kW to 300 kW. The structure of the tariff dictates that the highest of these values will determine the monthly power demand charge. To further illustrate this point, Table 3 contains the power demand charges, by period for the SRJ-optimal and peak-minimal cases.

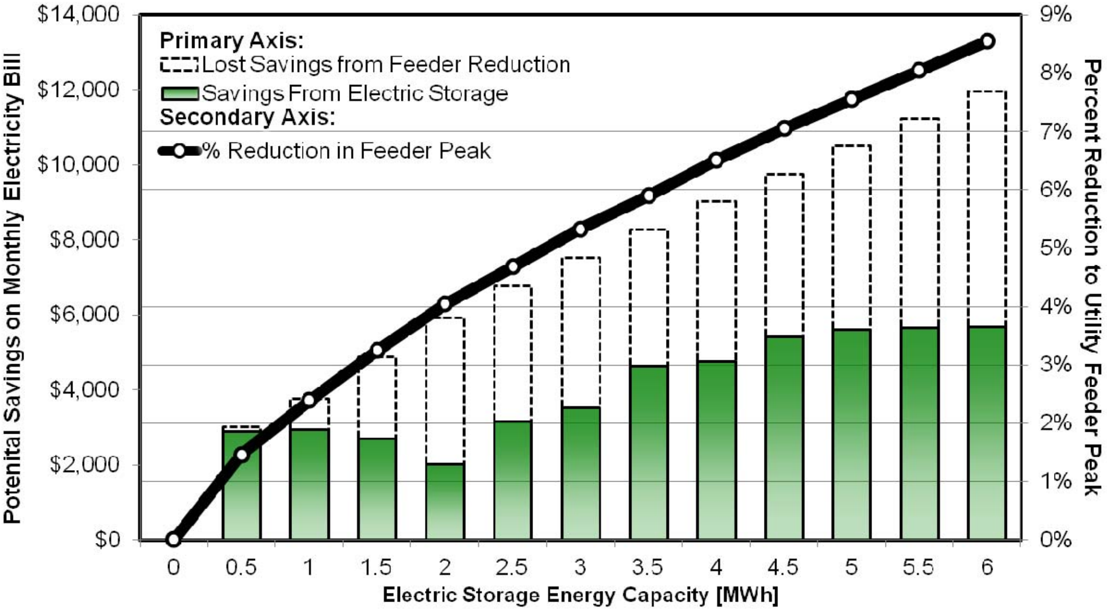
Table 3. Power Demand Charges by Period and Schedule Scenario

Period	**SRJ-optimal**	**Peak-minimal**
On-peak	$8,920	$12,195
Mid-peak	$3,098	$3,559
Off-peak	$0	$0
Max Monthly	$8,910	$10,236
Total	$20,928	$25,990

Lost value in the peak-minimal case comes predominantly from on-peak power demand charges (64%). Energy charges between these two scenarios are only slightly different, with the peak-minimal case costing a mere $60 less, which accounts for less than 1% of utility charges for energy during the week investigated. From this, it is clear that responding to feeder demand peaks will substantial impact the ability of a customer-operated microgrid to reduce its own demand charges. If the utility expects microgrids like SRJ to engage in this type of behavior, it will have to create incentives comparable to the lost savings outlined above.

Parametric Analysis of Electric Storage

Figure 8. Peak Reduction Potential and Lost Savings by Energy Capacity



The technical parameters of electric storage are an important factor in determining the potential, both in reducing power demand costs, as well as feeder peaks. Foremost among these parameters is energy capacity. As the previous analysis demonstrated, energy capacity was the key constraining factor in the feeder peak reduction potential. While the energy capacity of electric storage to be installed at SRJ has already been determined, a parametric analysis of energy capacity has been conducted to determine how it might increase peak savings potential. Additionally, for each battery, tariff rates are applied to both SRJ-optimal and peak-minimal cases, to determine how much savings potential is realized or lost by responding to the feeder peak. The results of this analysis are presented in Figure 8.

For small batteries, lost savings are low, because peak-shaving does not significantly interfere with reducing local on-peak demand. The feeder peak savings from such small batteries are modest, however. Once energy capacity reaches 2 MWh, lost savings become more significant, ranging between 44% and 65% lost. For feeder peak reduction, the marginal benefit of increased energy capacity appears to be decreasing with increasing battery sizes. Furthermore, above a capacity of 6 MWh, electric storage cannot reduce the feeder peak without having to resort to electricity export. SRJ is currently not compensated for electricity export, so above this point, lost savings potential would likely become even more significant. The largest battery considered—6 MWh—was able to produce a feeder peak reduction of 8.6%, falling short of the stated goal of 10% reduction. It was able to achieve this reduction at a cost of $6,288 in lost savings relative to the SRJ cost-optimal schedule. The lost savings arise primarily from power demand charges. This amounts to an effective cost of $735 per percent peak reduction per month. For batteries larger than 6 MWh, energy capacity is less crucial in determining the feeder reduction potential, rather power capacity, which determines the maximum discharge rate of electric storage, becomes the constraining factor. More importantly batteries above 6 MWh require electricity exporting to increase the effective feeder peak reduction. This analysis did not consider the possibility of exporting, and so such batteries were not included.

Conclusions

As this case study has shown, electric storage is capable of producing meaningful reductions to observed peak demand on utility feeders. However, such behavior will have substantial impacts on the customer-operated microgrid’s ability to reduce its own costs. In this instance, the DER-CAM produced peak mitigation strategy was able to realize a 6.5% feeder peak reduction at a cost of approximately $5,000. Because a large portion of SRJ’s monthly electricity bill stems from power demand charges, it is of critical importance that SRJ maintains low, flat power demand, especially during expensive on-peak periods. By responding to feeder conditions, facilities like SRJ will be unable to achieve this. Given this fundamental trade off, if utilities wish to encourage feeder peak mitigation behavior, they must either create incentives that match or exceed the expected loss in value of electric storage, or create alternative tariffs with more accommodating power demand charges during peak feeder events. This case study also demonstrated that while expanded energy capacity will increase peak reduction potential, it generally also increases the costs necessary to achieve those reductions.

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