San Marcos High School Solar Microgrid case study

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Introduction

Solar Microgrids are designed to provide indefinite solar-driven resilience to the most critical loads, at individual sites — and ideally throughout broad grid areas as well. San Marcos High School (SMHS) is a flagship of the Santa Barbara Unified School District (SBUSD) and serves over 2,000 grade 9-12 students. As can be seen in Figure 1, SMHS is in the middle of SBUSD's extensive territory, which is surrounded by extreme fire risk as well as risk from other natural disasters, including earthquakes and mudslides. Importantly, the entire Santa Barbara region is extremely vulnerable to grid outages, and energy resilience is increasingly recognized as a must-have, not just a nice-to-have.

The SBUSD recognizes the value-of-resilience (VOR) and has embraced the Clean Coalition's vision to implement robust Solar Microgrids at numerous schools and other critical SBUSD sites. Many of the Solar Microgrids are being implemented at critical life-sustaining facilities like SMHS, which serves as Red Cross emergency sheltering facility. The VOR at SMHS and other SBUSD sites is being evaluated accordingly. This case study tells the story of the SMHS Solar Microgrid and the critical benefits it provides.

Figure 1: The spread of SBUSD schools throughout Southern Santa Barbara County

San Marcos High School (SMHS) and its grid area

SMHS is a large integrated public high school serving over 2,000 grade 9-12 students. The school features the expected array of classroom and administrative facilities, along with a large pool, gymnasium, football stadium, multiple baseball fields, cafeteria, outdoor Greek theater, auditorium, and numerous tennis and basketball courts.

Figure 2: San Marcos High School

What is less obvious about SMHS, however, is that it sits in the middle of one of the most grid-vulnerable regions in California: the Goleta Load Pocket (GLP). As illustrated in Figure 3, the GLP spans 70 miles of California coastline and is served by just one transmission path routed through 40 miles of mountainous terrain, leaving the GLP highly transmission-vulnerable and disaster-prone. Southern California Edison (SCE), the utility serving the region, has identified the GLP's transmission path as being at risk for catastrophic failure from fire, earthquake, or heavy rains, which would cause a crippling, extended blackout of weeks or even months.

In addition to being broadly vulnerable to transmission grid outages, SMHS is at the heart of distribution grid outages and has been subjected to repeated Public Safety Power Shutoff (PSPS) actions. Figure 4 highlights the tremendous vulnerability of the transmission & distribution lines serving SMHS.

Figure 3: The Goleta Load Pocket consists of 70 miles of California coastline, spanning from Point Conception to Lake Casitas and encompassing the cities of Goleta, Santa Barbara (including Montecito), and Carpinteria

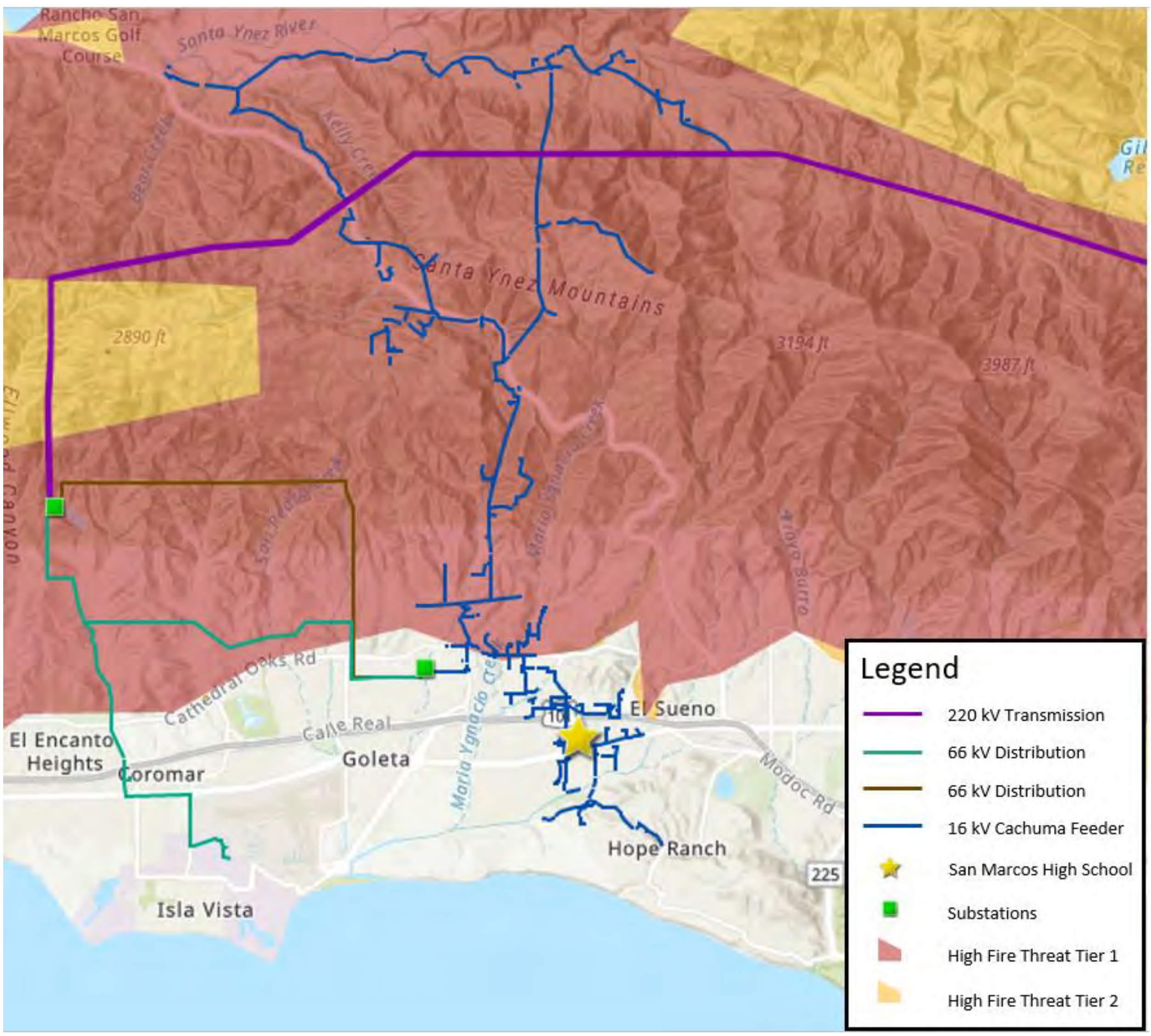

Figure 4: Map of transmission & distribution lines that serve SMHS, along with the extreme fire risk to the lines

SMHS Solar Microgrid overview

The SMHS Solar Microgrid will enable the school to operate independently during grid outages — and maintain its most critical loads indefinitely. In addition to providing indefinite resilience to most critical loads, the SMHS Solar Microgrid includes these features:

- **Solar:** 723 kWp in the form of solar parking canopies
- **Year-1 solar photovoltaic (PV) production:** 1,175,163 kWh
- **Year-1 solar offset of annual electricity consumption:** 101%
- **Battery Energy Storage System (BESS) energy capacity:** 710 kWh
- **BESS power capacity:** 355 kW
- **Critical (Tier 1) loads:** Refrigerators and freezers, maintained 100% of the time, indefinitely
- **Priority (Tier 2) loads:** Gym lights and Main Distribution Frame, maintained 80% of the time
- **Average Tier 1 load and percentage of total load:** 4.36 kW, 3.44%
- **Average Tier 2 load and percentage of total load:** 4.32 kW, 3.41%

Figure 5: SMHS Solar Microgrid site layout

In December of 2019, the SBUSD unanimously approved the initiative originally envisioned by the Clean Coalition to conduct feasibility analyses for and then stage Solar Microgrids throughout the majority of SBUSD sites. These Solar Microgrids are anticipated to be operational by summer 2021. Importantly, Electric Vehicle Charging Infrastructure (EVCI) is also anticipated to not only support staff and students during the day, but also provide overnight charging options for neighbors who have challenges installing electric vehicle chargers where they live. Table 1 summarizes Solar Microgrid features across the target SBUSD sites, including solar and BESS sizing.

Site name	PV system size (kWp)	Year-1 PV production (kWh)	Offset of annual onsite energy consumption by PV system, Year 1 (%)	BESS energy capacity (kWh)	BESS power capacity (kW)	BESS duration without PV (hours)	SOCr [a] average (kWh)	SOCr [a] percent of total battery
Adams ES	114	181,629	93%	244	122	2	16.2	6.6%
Cleveland ES	64	105,490	108%	74	37	2	10.8	14.6%
Facilities and maintenance warehouse	83	137,270	100%	450	75	6	81.1	18.0%
SBUSD Office and La Cuesta HS	158	258,861	100%	396	99	4	8.5	4.3%
Dos Pueblos HS	1,116	1,772,368	90%	994	497	2	36.8	3.7%
Franklin ES and Adelante Charter	228	366,911	98%	256	128	2	33.6	13.1%
Goleta Valley JHS	274	449,582	105%	370	185	2	21.7	5.9%
La Colina JHS	258	373,319	100%	304	152	2	26.5	8.7%
La Cumbre JHS and SB Community Academy	307	499,150	101%	336	168	2	18.4	5.5%
Monroe ES	107	179,425	94%	244	61	4	34.4	14.1%
Roosevelt ES	116	191,639	79%	410	205	2	5.7	1.4%
Santa Barbara HS	661	1,076,796	84%	726	363	2	36.0	5.0%
Santa Barbara JHS	219	354,465	85%	350	175	2	25.4	7.3%
San Marcos HS	723	1,175,163	101%	710	355	2	28.5	4.0%
Washington ES	96	166,138	101%	122	61	2	11.3	9.3%
Totals	4,523	7,288,206	94%	5,986	2,683	n/a	394.9	6.8%

Table 1: Summary of SBUSD Solar Microgrid sizing and performance characteristics

Load tiering and valuing resilience ("VOR123" methodology)

The Clean Coalition's value-of-resilience (VOR) methodology begins by tiering loads into three categories: Tier 1 being critical loads, Tier 2 being priority loads, and Tier 3 being discretionary loads. This methodology is referred to as VOR123.

Load tiering is a crucial part of ensuring that indefinite renewables-driven backup power can be provisioned to the most critical loads — and significant resilience can be provisioned to priority loads as well. In the case of SMHS, the following loads have been deemed to be Tier 1, Tier 2, and Tier 3:

- **Tier 1: Freezers and refrigerators**. Only main foodservice units are considered to be critical, and no special considerations have been made for small refrigerator units in teacher lounges and/or nursing offices etc.
- **Tier 2: Main Distribution Frame (MDF**) facilities for communications services and primary Multi-Purpose Room (MPR) type facilities for emergency response. The MPR at a particular site should be a cafeteria, gym, auditorium, or an officially specified MPR.
- **Tier 3**: All other loads.

The anticipated resilience for these load tiers, in terms of percentage of time online, is as follows:

- Tier 1: 100%
- Tier 2: 80% (at least)
- Tier 3: 25% (at least)

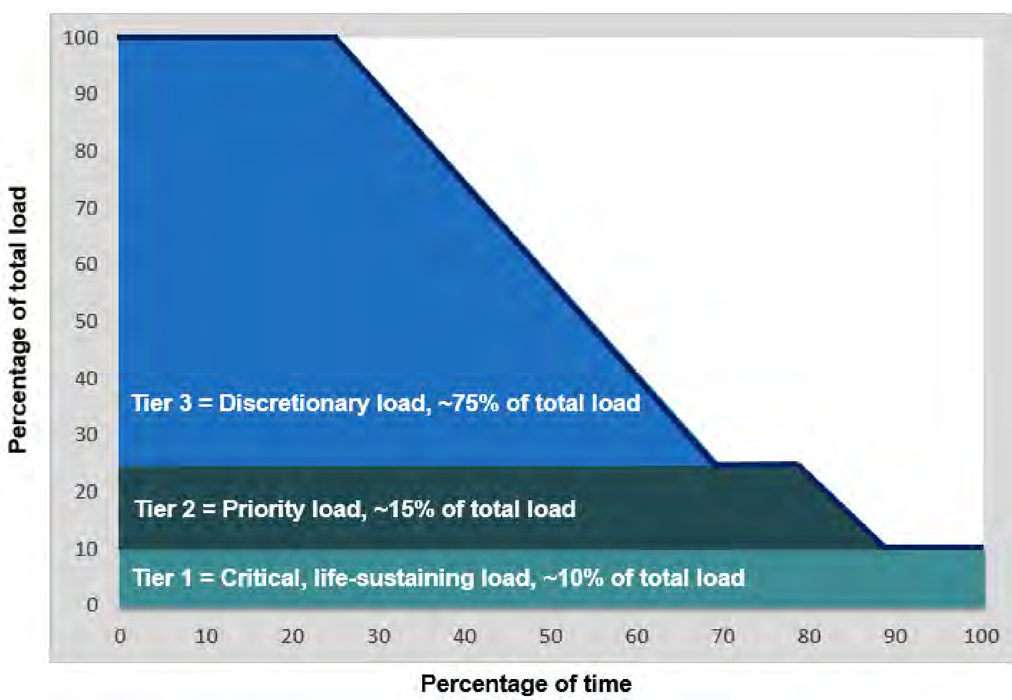

Figure 6: Resilience levels by load tier for a Solar Microgrid at UC Santa Barbara (UCSB) with a net zero level of solar and BESS energy capacity equal to 2 hours of solar production (1 MW of solar and 2 MWh of storage, for example)

With respect to valuing resilience, there are different VOR levels for each of the three load tiers. The following valuation ranges are typical for most sites:

- **Tier 1**: 100% resilience is worth approximately 3 to 5 times the normal price paid for electricity. In other words, indefinite energy resilience for critical loads is worth 3 to 4 times the normal price paid for electricity. Given that the typical facility has a Tier 1 load that is about 10% of the total load, applying the low side of the Tier 1 VOR multiplier typically yields a 20% adder to the pre-resilience electricity rate.
- **Tier 2**: 80% resilience is worth approximately 1.5 to 3 times the normal price paid for electricity. In other words, energy resilience that is provisioned at least 80% of the time for priority loads is worth 1.5 to 2.5 times the total, so applying the low side of the Tier 2 VOR multiplier yields a 7.5% adder on top of the pre-resilience electricity rate.
- **Tier 3**: Although a standard-size solar microgrid can provide backup power to Tier 3 loads a substantial percentage of the time, Tier 3 loads are by definition discretionary, and therefore, a Tier 3 VOR multiplier is negligible and assumed to be zero.

Taken together, the Tier 1 and Tier 2 premiums for a standard load tiering allocation yields an effective VOR of between 25% and 30%. Hence, the Clean Coalition uses 25% as the typical premium that a site should be willing to pay for indefinite renewables-driven backup power to critical loads — along with renewables-driven backup for the rest of the loads for significant percentages of time.

VOR123 value-of-resilience (VOR) adder validation

Although SBUSD Tier 1 and Tier 2 load allocations are mostly on the lower side, averaging 6% and 7% of the total load respectively, yielding overall VOR ranges between about 10% and 40%, the Clean Coalition believes that the 25% centerpoint makes sense to apply as the standard overall VOR, which is applied to existing electricity rates. Across the SBUSD sites, the standardized 25% VOR yields an average Solar Microgrid adder of about 4 cents/kWh (25% of the overall average 16.1 cents/kWh 2019 average electricity rate across all 15 SBUSD sites evaluated for Solar Microgrids).

Importantly, the Clean Coalition has resolved on the general 25% VOR figure for typical sites after conducting numerous analytical validation analyses, including the following three primary validation approaches:

1. Cost-of-Service (COS): COS is the cost that suppliers will charge in order to offer the Solar Microgrid VOR across the Tier 1, 2, and 3 loads (“VOR123”). As evidenced by the data in Tables 4, 5, and 6; a COS that reflects a 25% resilience adder over each site’s individual 2019 electricity rate yields Solar Microgrids that are cost-effective at the largest SBUSD sites. While the overall average adder is 4 cents/kWh across all SBUSD, the largest SBUSD sites have lower electricity rates — and thus the 25% adder is lower at the largest SBUSD sites.

2. Department of Energy (DOE) Multiplier: The DOE researched VOR and determined that the overall value of critical load that is missed due to grid outages over an annual period is $117/kWh. While the Clean Coalition stages Solar Microgrids to provide indefinite solar-driven backup power to critical loads, and considers 30 consecutive days to be a proxy for indefinite, the Clean Coalition

assumed a conservative annual cumulative outage time of 3 days for the DOE Multiplier VOR analysis. Over the SBUSD's prototypical schools, this analysis yields an overall 30% VOR adder to the 2019 electricity spend, as delineated in Table 2.

Prototypical School	Average Tier 1 Load (kW)	Tier 1 kWh/year missed (72 hours/year)	VOR ($117/kWh)	Total 2019 electricity spend	DOE-derived VOR % of 2019 spend
Franklin ES	4.7	336	$39,256	$70,000	56%
La Cumbre JHS	2.8	202	$23,587	$78,000	30%
San Marcos HS	4.4	314	$36,729	$188,000	20%
Totals	11.8	851	$99,572	$336,000	30%

Table 2: DOE Multiplier results for prototype SBUSD schools

3. Market-Based: This is essentially the market price, where supply meets demand, and the Direct Relief Solar Microgrid provides a local case study. Direct Relief has deployed a Solar Microgrid with 320 kW of solar PV and a 676 kWh BESS and purchases the solar energy via a roughly breakeven Power Purchase Agreement (PPA). The BESS, however, is leased at an annual cost of $37,500. While the size of the Direct Relief BESS (676 kWh) is a bit smaller than the size of the San Marcos Solar Microgrid BESS (710 kWh), Direct Relief is paying a bit more ($37,500/year) than the DOE Multiplier would value the San Marcos BESS ($36,729/year, as shown in Table 2).

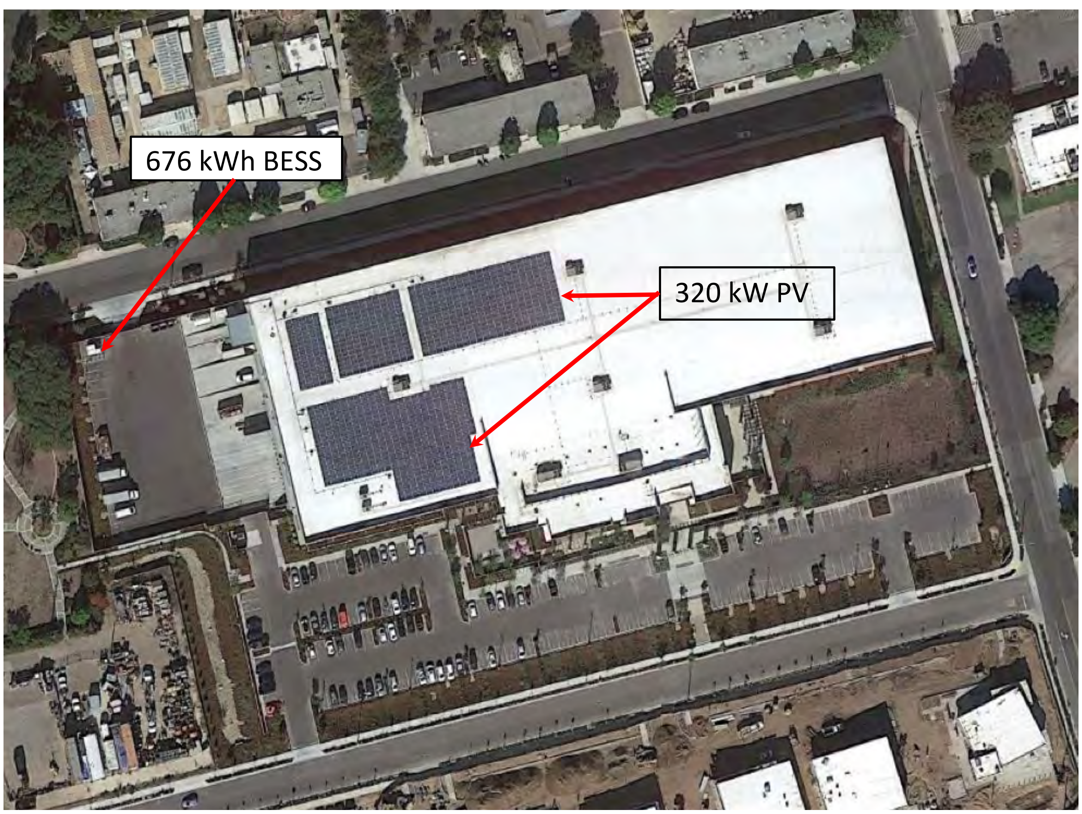

Figure 7: Direct Relief and its Solar Microgrid solar PV and BESS components

State of Charge for resilience (SOCr)

In order for a Solar Microgrid to optimize economic performance while always being ready to provision indefinite renewables driven-backup power to critical loads, the Solar Microgrid needs to always be ready to operate in these two fundamental modes:

1. Normal grid-connected operations: In normal operations, with the exception of a minimum BESS State of Charge (SOC) reserved for resilience (SOCr), the entire usable BESS energy capacity should be available for daily cycling in pursuit of economic optimization, as illustrated in Figure 8. In order to maximize economic performance, the SOCr should always be minimized, and high-fidelity SOCr values should be calculated regularly, based on load and solar forecasts. The Clean Coalition's SOCr algorithm updates every 15 minutes.
2. Emergency grid-outage operations: In emergency operations, during grid outages, the site is entirely powered by the Solar Microgrid, with the solar and BESS being dedicated to serving onsite loads according to the specified tiering prioritization.

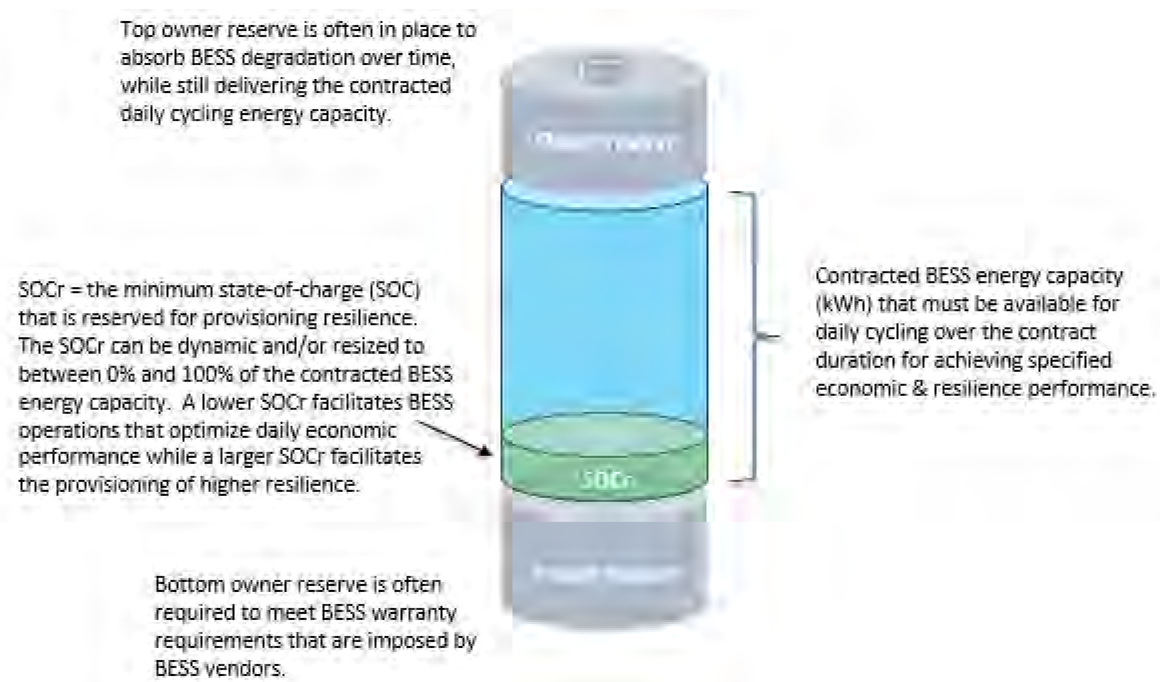

Figure 8: State of Charge for resilience (SOCr)

Importantly, a site must be able to override SOCr settings to between 0% and 100% of the daily usable BESS energy capacity. For example, if preferences increase for everyday economic optimization, then the site can set lower SOCr levels. Conversely, in the face of coming storms and/or PSPS warnings, the site can set higher SOCr levels to prepare for the increased likelihood of grid outages and associated energy resilience needs.

For the SMHS Solar Microgrid, Tier 1 (critical) and Tier 2 (priority) loads were sized and SOCr values were calculated at every 15-minute interval in order to size the BESS and analyze the economic performance of the Solar Microgrid design. Table 3 shows key metrics for Tier 1 loads, Tier 2 loads, and the range of SOCr values over the annual period that was analyzed.

Site Name	Electrical Load	Load Tier	Number of Panel Levels to Load	Avg Load (kW)	Average Critical Load of Total Load - Percentage	Avg SOCr (%)	Max SOCr (%)	Min SOCr (%)
San Marcos HS	Refrigerators & Freezers	1	3	4.36	3.44%	4.0%	6.3%	2.7%
	Gym/Multipurpose room li	2	3	3.60	2.84%			
	Main Distribution Frame	2	4	0.72	0.57%			

Table 3: San Marcos High School critical load and SOCr calculations

Applying VOR in evaluating Power Purchase Agreement (PPA) rates

The staging of Solar Microgrids at SBUSD sites included designing and executing a Request for Proposal (RFP) process to select a developer to build, own, and operate the Solar Microgrids under a long-term Power Purchase Agreement (PPA). The specified PPA structure ensures that the SBUSD avoids any upfront investments and any other obligations beyond paying for delivered energy. Hence, the SBUSD will pay only for solar-generated electricity, whether delivered in real-time when the sun is shining or time-shifted via the BESS for delivery at other times when electricity is more valuable.

The SMHS Solar Microgrid was a critical component of the SBUSD RFP design, as SMHS was the school used to set the baseline understanding for all SBUSD sites. The RFP proposal deadline is in mid-July 2020, with Solar Microgrids scheduled to be fully operational by summer 2021.

In the feasibility analyses, the Clean Coalition applied the VOR123 methodology to estimate the overall VOR of indefinite solar-driven resilience to the most critical SBUSD loads — and validated the standard 25% VOR adder across all SBUSD sites. Findings show that the largest SBUSD sites, including SMHS, enjoy favorable Year-1 economic benefits from Solar Microgrids. Table 4 summarizes the full value of electricity across the SBUSD sites, including with the 25% VOR adders. Table 5 and Table 6 highlight anticipated PPA pricing that is below the threshold value of electricity, including VOR adders (see green-highlighted cells). Importantly, economics improve over time as utility rates increase more than any potential PPA escalators.

Site name	2019 cost and values (¢/kWh)			
	Annual cost/kWh	PV value	PV+BESS value	PV+BESS+ VOR
Adams ES	17.8	12.7	14.5	19.0
Cleveland ES	18	12.2	13.4	17.9
Facilities and Maintenance Warehouse	15.8	11.6	16.4	20.4
SBUSD Office and La Cuesta HS	17.7	13.7	13.8	18.2
Dos Pueblos HS	14.9	10	12.2	15.9
Franklin ES and Adelante Charter	16.8	12	13.7	17.9
Goleta Valley JHS	16	11.5	12.5	16.5
La Colina JHS	16.2	12.1	13.1	17.2
La Cumbre JHS and SB Community Academy	15.6	12.2	12.9	16.8
Monroe ES	16.8	12.7	14.7	18.9
Roosevelt ES	17.8	12.6	16.1	20.6
Santa Barbara HS	14.5	11.9	14.6	18.2
Santa Barbara JHS	16.1	12.5	15.7	19.7
San Marcos HS	15.3	11.7	12.9	16.7
Washington ES	17.5	12.6	14.1	18.5
Weighted average total	16.1	11.6	13.5	17.5

Table 4: Summary of energy costs and values for year 2019

Site name	25-year fixed PPA pricing, 0% escalator (¢/kWh)					
	Annual cost/kWh	PV	PV+ BESS	PV+BESS+ MLM	PV+BESS+ CLP	PV+BESS+ FAM
Adams ES	17.8	16.0	18.5	21.5	25.5	26.5
Cleveland ES	18	17.0	18.5	25.0	32.0	34.0
Facilities and Maintenance Warehouse	14.9	16.5	16.5	16.5	22.0	23.5
SBUSD Office and La Cuesta HS	15.8	16.0	16.0	18.0	24.0	27.0
Dos Pueblos HS	16.8	13.0	14.0	14.5	15.0	15.5
Franklin ES and Adelante Charter	16	15.5	15.5	16.5	18.5	19.0
Goleta Valley JHS	16.2	15.0	16.5	18.0	20.5	21.5
La Colina JHS	17.7	15.0	16.5	17.0	23.0	26.0
La Cumbre JHS and SB Community Academy	15.6	15.0	15.0	16.0	18.0	19.5
Monroe ES	16.8	16.5	18.0	21.5	25.5	27.0
Roosevelt ES	17.8	16.0	19.0	21.5	25.5	26.5
Santa Barbara HS	15.3	14.0	15.0	16.0	17.0	18.0
Santa Barbara JHS	14.5	15.5	17.0	19.0	22.0	24.0
San Marcos HS	16.1	14.0	15.0	16.0	17.0	17.5
Washington ES	17.5	16.5	18.0	22.0	26.5	27.5
Weighted average total	16.1	14.2	15.2	16.5	18.5	19.5

Table 5: Summary of PPA pricing at 0% annual escalator

Site name	Year-1 PPA pricing, 3% escalator (¢/kWh)					
	Annual cost/kWh	PV	PV+ BESS	PV+BESS+ MLM	PV+BESS+ CLP	PV+BESS+ FAM
Adams ES	17.8	13.0	15.5	18.5	22.5	23.5
Cleveland ES	18	14.0	15.5	22.0	29.0	31.0
Facilities and Maintenance Warehouse	14.9	13.5	13.5	13.5	19.0	20.5
SBUSD Office and La Cuesta HS	15.8	13.0	13.0	15.0	21.0	24.0
Dos Pueblos HS	16.8	10.5	11.5	12.0	12.5	13.0
Franklin ES and Adelante Charter	16	12.5	12.5	13.5	15.5	16.0
Goleta Valley JHS	16.2	12.0	13.5	15.0	17.5	18.5
La Colina JHS	17.7	12.0	13.5	15.5	18.5	20.0
La Cumbre JHS and SB Community Academy	15.6	12.0	12.0	13.0	15.0	16.5
Monroe ES	16.8	13.5	15.0	18.5	22.5	24.0
Roosevelt ES	17.8	13.0	16.0	18.5	22.5	23.5
Santa Barbara HS	15.3	11.5	12.5	13.5	14.5	15.5
Santa Barbara JHS	14.5	12.5	14.0	16.0	19.0	21.0
San Marcos HS	16.1	11.5	12.5	13.5	14.5	15.0
Washington ES	17.5	13.5	15.0	19.0	23.5	24.5
Weighted average total	16.1	11.7	12.8	14.1	16.0	17.0

Table 6: Summary of PPA pricing at 3% annual escalator

Load Management configurations

Load Management is fundamental to Solar Microgrid operations and the VOR123 methodology. As an example, the SMHS Solar Microgrid requires Load Management that, at a minimum, provides the following functionality:

1. Disconnects seamlessly from the grid upon grid outages and reconnects seamlessly upon grid restoration, while serving the grid-forming function during grid outages.
2. Maintains Tier 1 loads indefinitely, while having black-start capability in the extreme case that a catastrophic failure temporarily shuts down a Solar Microgrid.
3. Maintains Tier 2 loads as long as possible without threatening the ability to maintain Tier 1 loads. Additionally, maintains Tier 3 loads, ideally in a programmable prioritized order, but otherwise as a group. This essentially means that Tier 3 loads are anticipated to be energized only when solar energy is plentiful and the BESS is near its storage capacity such that additional solar generation is likely to be curtailed.

Although there are multiple potential Load Management configurations, the minimal functionality anticipated to be cost-effectively implemented is referred to as the Critical Load Panel (CLP) approach. The CLP name reflects the requirement for a smart critical load panel that maintains Tier 1 loads indefinitely and toggles Tier 2 loads. In the CLP approach, Tier 3 loads will be toggled as a group by toggling power to the Main Service Board (MSB). Figure 9 illustrates the CLP approach for SMHS, with Tier 1 and Tier 2 loads being served by new dedicated wire runs that connect to a new smart critical load panel.

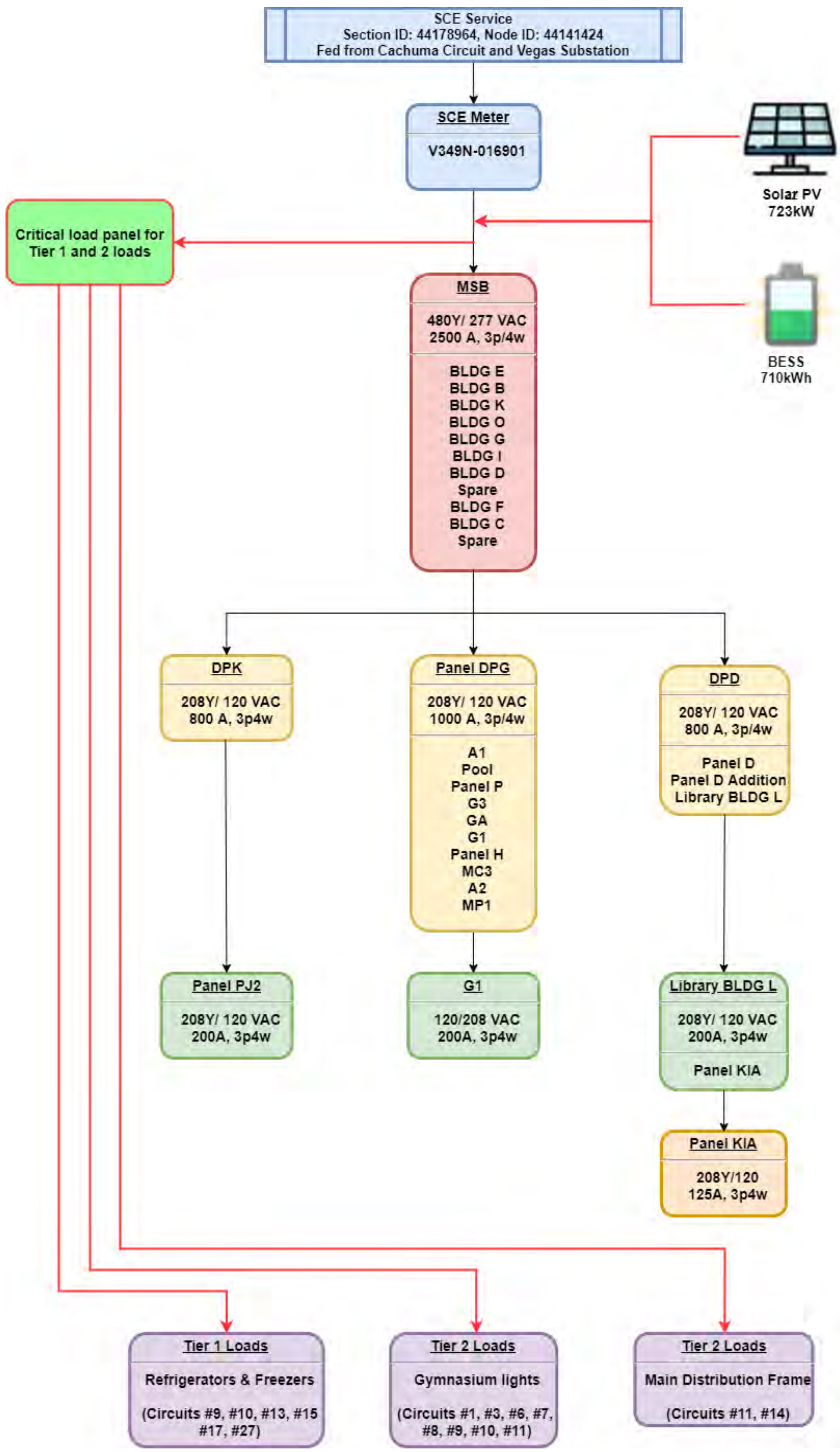

Figure 9: SMHS Solar Microgrid circuit flow diagram for the Critical Load Panel (CLP) approach