Considerations for Battery Energy Storage System on University of California Davis Campus

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Executive Summary

UC Davis received 2.1 million dollars in funding to install a 3 MWh Tesla Megapack battery energy storage system (BESS) on its campus for the purpose of load shifting. While the installation location for this BESS has already been decided, the UC Davis Utilities Department is curious if more BESS should be added to the campus grid. Our team was asked to review how other college campuses have used this technology and to justify future suitable BESS sites on the Davis campus. Considerations for site analysis include existing electrical and civil infrastructure, transformer specifications, physical space, and building electrical demand. The installation site is dependent on the intended BESS application, so the results of this report are primarily applicable for load shifting assets. Our team was tasked with reviewing the BESS integration of other college campuses and justifying some well-suited sites on Davis's campus. The three identified sites well-suited for future campus battery energy storage systems were the Center for Companion Animal Health, Contained Research Facility, and the Student Health and Wellness Center.

Project Background

Load Shifting

Load shifting involves moving the electrical demand from one time to another utilizing energy storage systems. This concept is illustrated in Figure 1 [1]. BESS can time-shift energy flows depending on the goal of the user. One example of load shifting known as arbitrage involves charging the BESS when energy costs are low and discharging when the costs are higher. Another example stores energy when grid emissions intensity is low (e.g. afternoons with high solar generation) and discharges when generation is predominantly from high-CO_2 emitting sources. Other applications for BESS are described in the **Literature Review** section.

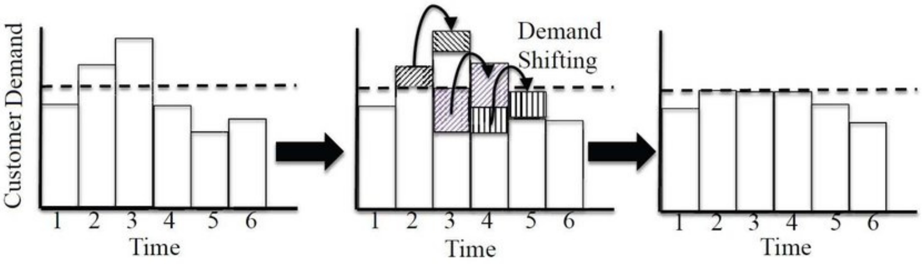

Figure 1. Load (demand) shifting [1]

Current BESS Site Selection

A site for the Tesla BESS was identified by staff electrical engineers and the High Voltage team at UC Davis prior to our involvement in the project. The battery system will be connected to a transformer serving the Animal Husbandry Feed Mill site as shown in Figures 13 and 14

(**Appendix**). This transformer is rated at 1000 kVA and 480V (3Ø AC). The existing loads on the building include a base for lighting and plug loads of roughly 10 kW, and an equipment peak load of three milling units operating roughly at 85 kW each. Assuming a power factor of 0.8, peak building load was roughly calculated to 438 kVA, facilitating more than 500 kVA of charging capacity under peak demand scenarios. The BESS will likely be charged at its maximum rating as milling typically occurs during evening discharge hours when the BESS is alleviating transformer demand via dispatching its own power. With plenty of physical space consisting of gravel and essentially no existing underground utilities, this location was approved and included in the funding report sent to the CPUC in March of 2023.

Other BESS Applications

There are many different applications for battery energy storage systems, and the intended application is one of the guiding factors for site selection. For example, if the asset is intended to serve as backup power for a critical load, the site selection will be quite different than if it is intended for reducing campus peak demand. Some notable, common applications for BESS include and are not limited to:

Load-leveling

BESS can time-shift energy flows in order to smooth load patterns by load-leveling, which is when the on-peak demand is reduced and off-peak demand is increased. Additionally, from an optimization standpoint, the optimal charging and discharging policies are often to minimize the difference between the peak and valley demand, and to minimize the daily variance in load, e.g. load-leveling [2]. This reduces the load on the distribution grid, especially when it is using uneconomical generation facilities during peak demand hours.

Peak shaving

Reducing the peak of the load profile of a site often lessens the planning and operational costs associated with powering that site. This is because it reduces or eliminates the need to build new central generation capacity, upgrade existing infrastructure, or to purchase capacity in the wholesale electricity market [3]. Peak shaving keeps the loading of the transmission and distribution system equipment below a specified maximum, which allows for delays in transmission upgrades. It can also help avoid the need to completely upgrade a transmission system and helps to mitigate congestion-related costs.

Power quality

The increased adoption of electric vehicles and the integration of distributed power generation, such as intermittent renewables (e.g. solar and wind), is expected to have a negative impact on power quality in distribution networks [4]. Using a decentralized energy management system for EV charging and renewable power smoothing can mitigate those negative effects. Power quality is an important consideration when operating grids; its main factors are shown in Figure 5

(**Appendix**), and a deeper description of some of the most relevant factors is given in Table A1 (**Appendix**).

Title 24 BESS Expansion

Developed by the California Energy Commission and approved by Governor Gavin Newsom, the 2022 Building Energy Efficiency Standards, commonly referred to as Title 24, mandates the addition of photovoltaic and battery storage energy systems with the development of nonresidential California buildings in Part 6 section 140.10. Tables 140.10A and 140.10B state that for every development project (larger than 5,000 sq ft) at a school or university, a minimum photovoltaic capacity of anywhere from 1.27-2.46 W/sq ft is required (dependent on Climate Zone), and a energy storage to photovoltaic capacity ratio of 1.87 Wh/W must be developed [15]. This means that for each new campus expansion and redesign, the University must ensure sufficient battery storage capacity is attributable to the project. Therefore, it is highly likely that the alternative sites selected in this report will be considered for BESS expansion under Title 24 in the near future.

Literature Review of Relevant BESS Installations

Robert Mondavi Institute (RMI) Winery, UC Davis

A commercial scale microgrid was designed and constructed on UC Davis campus in order to provide power to the RMI Winery [5]. This microgrid was primarily used to reduce peak-time energy use, according to the direction of the California Energy Commision (CEC), who funded the work. The CEC's main concern was reducing the duck curve, as described in the **Load Leveling** section of this paper. There were two buildings involved in the microgrid: the Brewery Winery and Food Science Building (BWF) and the Jackson Sustainable Winery Building (JSWB). The microgrid included a 164.5 kW solar photovoltaic (PV) system, a 262 kWh BESS, and a custom energy management system (EMS). Something unique about the BESS is that all the batteries used in it were second-life Nissan Leaf EV batteries, meaning that they were used in Nissan Leafs until they were retired, then repurposed for use in the storage system.

UC San Diego

UC San Diego has one of the most diverse energy storage portfolios and one of the most advanced microgrids among universities in the world [6][7]. The campus grid is connected to San Diego Gas & Electric (SDG&E). The campus grid has submetered and controllable loads, renewable energy resources such as a 3 MW PV farm and 2.8 MW fuel cell, a cogeneration plant (natural gas-fired plant with two 13.5 MW turbines and 3 MW steam turbine), and a 2.5MW/5MWh BESS that was installed in 2015 but has since degraded to 1.8MW/3.6MWh [8].

UC San Diego became eligible for around $3.25 million in financial incentives for this BESS through the Self-Generation Incentive Program (SGIP), the same program that is funding UC Davis to install the 3 MWh BESS described in the **Executive Summary**. UCSD's 5 MWh BESS was purchased from BYD, one of the largest suppliers of rechargeable batteries. The birds-eye view of the BESS and surrounding utilities is shown in Figure 6 (**Appendix**), and its single-line diagram is shown in Figure 7 (**Appendix)**. Since UCSD's 12 kV grid system is nodal in nature, the BESS could be connected to it anywhere on campus. Since there was already an available 12 kV switch at the location it was eventually installed at, the BESS was simply tied into that. The project provided all the transformers and the 12 kV circuit breaker required for when paralleling sources.

According to John Dilliot, UCSD's Director of Utilities & Sustainability, UCSD was initially driven to install this BESS because of the payback of the project [8]. The payback was calculated from avoided demand costs. The SGIP incentive for advanced energy storage (AES) could cover up to 60% of the total cost. The bid came in at around $6M, resulting in a net cost of $2.75M and simple payback of 5.6 years, which was well within the financial requirements.

The BESS is used for general campus-wide demand charge mitigation, but UCSD found that they could generate more revenue via the CAISO DRAM program [8]. UC San Diego participates in the Demand Response Auction Mechanism (DRAM), which is a CAISO wholesale market demand response platform that is only active during the peak load period (4-9 PM) [6]. The utility imports to the campus grid are the total campus load minus on-site generation and BESS dispatch. The utility import is the variable bid into DRAM since it is the only variable measured by the meter provided by SDG&E. The BESS is the only easily controllable demand response resource on campus, so optimal control algorithms developed for BESS control only optimize the BESS dispatch [6].

Overall, the investment in the BESS has been worth it for UCSD [8]. First, the payback ended up being better than they thought as SDG&E raised demand charges over time. Additionally, there was an increase in revenues from the DRAM program. There have not been many cons, as from a technical point of view the system is relatively simple. The biggest con has been the upkeep and maintenance of the system. After the first few years, there seemed to always be something that needed attention in regards to the various system components. The battery controllers have many devices to control and monitor the internal temperatures of the battery strings, and they needed more attention than was originally anticipated. Since the manufacturer (BYD) is Chinese, the technical support is from China. The language barrier has been somewhat challenging because when something needs to be fixed, BYD cannot talk UCSD facilities staff through it. Someone from BYD ends up having to come, so there is an additional lag due to the travel.

Alternative Site Selection

Selection Criteria

For battery energy storage systems to be implemented onto the UC Davis electrical grid, there needs to be a transformer serving as an interface between the two systems to step down the 12.47 kV distribution. In the case for Tesla’s 3 MWh Megapack, the transformer output voltage needs to be at 380–505 V AC 3-phase and capable of up to 929.5 kVA for a 4 hour dis/charge [12]. Given these specifications, the transformer would need to be rated at 480V (3Ø AC) and at 1000+ kVA . Given the supply shortage of electrical steel, distribution power transformers are currently hard to obtain, with wait times currently at 1-2 years [13]. For this reason, only existing transformers on campus should be considered.

With UC Davis being a university consisting of offices, classrooms, housing, labs, and community spaces, each building is significantly different when it comes to its electricity demand [14]. Office buildings use significantly less energy than lab buildings, but they tend to have lower voltage and power rated transformers which is not ideal for BESS implementation. There can also be multiple transformers serving one building or transformer(s) serving multiple buildings. This makes calculating the building demand more complex as it is sometimes hard to distinguish how much load is on a specific transformer. To simplify the process, transformers that exclusively serve one building would take priority to make the calculation of transformer load availability easier.

Calculating available transformer capacity gives an estimate of how fast the BESS can be charged. Available transformer capacity is calculated by subtracting the maximum building load (kW) divided by the power factor (PF) from the serving transformer nameplate rating (kVA). The maximum load is used to ensure peak demand on the transformer is taken into account. An ideal space would have 929.5 kVA or more available to allow the maximum charge rate of 750 kW for four hours under the manufacturer’s power factor of 0.807 [12].

Other important factors in site selection include physical space and avoidance of underground utilities. The BESS will be located near the transformer it is connected to, so there has to be enough space to put the 23.52 ft x 5.43 ft x 8.27 ft body [12]. Within that space, there should be little to no underground utilities (natural gas, hot water, chilled water, steam, sewer, etc.) as the BESS is required to be anchored for seismic purposes. Avoidance of such lines minimizes the overall installation cost and project complexity.

Methods

Tools & Applications

Excel was used to evaluate site feasibility by organizing decision variables, keeping track of transformer specifications and relevant building information, and performing calculations to determine if sites satisfied the necessary requirements see Figure A4 (**Appendix**)

UC Davis's single line diagrams shown in Figure 9 (**Appendix**) were used to find transformers of 480V (3Ø AC) and at 1000+ kVA. These diagrams gave us information regarding the transformers, the buildings which they serve, the feeder connecting them, and nearby pull boxes. This information allowed us to determine initial viability of transformers, and narrow our search down based on whether or not sites had appropriate existing infrastructure to minimize installation costs.

After transformer specifications were determined and recorded, the team utilized Campus Map shown in Figure 10 (**Appendix**) to locate relevant buildings and align nomenclature between the single line diagram and the next tool discussed, Facilities Map.

Having established where to find the building, further information regarding transformer connections, underground utilities, and physical space could be found through Facilities Map as shown in Figure 11 (**Appendix**). With the ability to overlay underground utility lines, access aerial views of sites, and verify electrical connections, this software was the main source of information for establishing site feasibility based on our selection criteria.

Once selection criteria were validated through the use of Facilities Map, the kVA of transformers were compared to the electrical demand of the building(s) they served. Building electrical demand was calculated using AVEVA PI Vision, and referenced historical trend data from the last year of operation such as in Figure 12 (**Appendix**). Both the mean and maximum demand of the served buildings were recorded and added to the Excel spreadsheet. In order to be considered a suitable site the transformer needed to have 750-1000 kVA of "available" capacity to allow for a charge time deemed reasonable of less than five hours. A smaller available transformer capacity would lead to excessively long charge times, and would hinder the efficacy of load shifting.

Load Profile Calculations

In the case of Figure 12 (**Appendix**), Valley Hall's electricity demand was graphed. The building had three electrical demand tags: MSB (main switchboard), MSBH1, and MSBE (emergency), which were summed to determine the total electrical demand of the building. The number of meters at each building varied, so recording all demand-related trend data of the building was vital to accurately calculating the total load (kW).

$$\begin{aligned} Valley\ Hall\ Load = Max\ Electricity\ Demand &= MSB + MSBH1 + MSBE \\ &= 174.6 + 28.1 + 18.567\ kW \\ &= 221.267\ kW \end{aligned}$$

In order to calculate the available capacity on the transformer, the nameplate capacity is first referenced, and diminished by the maximum demand of the building(s) it serves. Valley Hall has a 1000 kVA transformer, so the remaining capacity of the transformer is:

$$\begin{aligned} Transformer\ Availability &= Transformer\ Nameplate\ Rating - Building\ Load/PF \\ &= 1000\ kVA - 221.267\ kW/0.807 = 725.82\ kVA \end{aligned}$$

With this kVA calculated, even under the maximum annual demand scenario, the BESS would be able to charge at 725.82 kVA (586 kW) in a little over five hours.

Results and Discussion

After applying the above procedure to analyze the feasibility of installing the BESS to all relevant transformers on UC Davis's campus, we identified the three best suited sites:

1) Center for Companion Animal Health

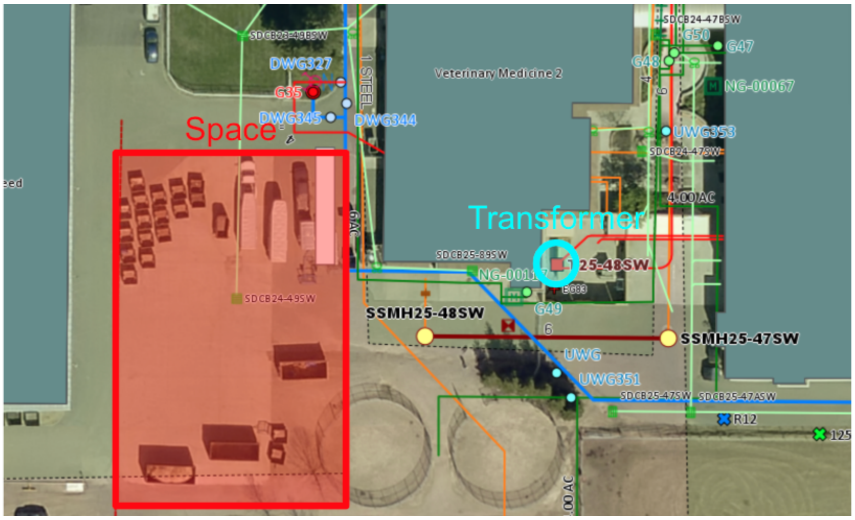

Figure 2: CCAH site

This site has a 1500 kVA transformer, with 1069 kVA available on the transformer during peak demand scenarios. This building is located southwest of the main campus, in the veterinarian medicine area. There is plenty of space to put a battery energy storage system with little utilities in the way. It must be noted that this area is next to horse corrals.

2) Contained Research Facility

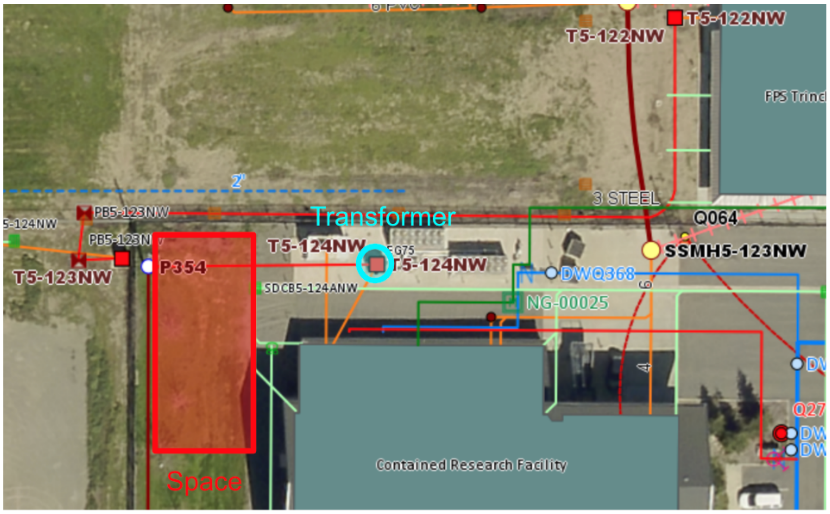

Figure 3: CRF site

This site has a 1500 kVA transformer, with 879 kVA available on the transformer under peak demand. This building is located far west and is not a part of the main campus. From looking at the aerial view on Google Maps, there are now trees by the fence that can provide shade to the BESS. This may prove useful in extending the life of the BESS and minimizing the stress on the battery management and cooling systems.

3) Student Health and Wellness Center

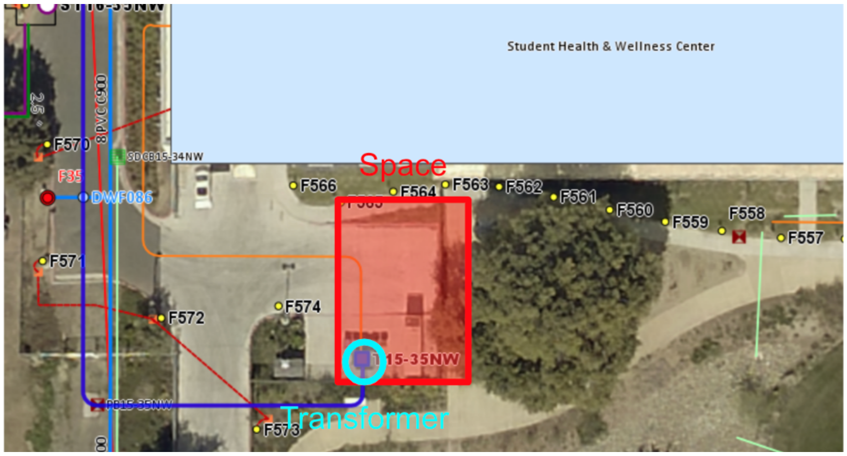

Figure 4: SHWC site

This site has a 1000 kVA transformer, with 752 kVA available on the transformer. This building is located on the outskirts of the main campus, northwest. Similar to the CRF site, there is a tree nearby that can provide partial shade to the BESS.

Conclusion

Based on the BESS installation at UCSD, BESSs have a much higher financial incentive when revenue can be generated from demand response and when existing electrical infrastructure can be used. Learning from other college campus BESS applications can enhance UCD's considerations when deciding on future BESS installations; therefore, the client should read the more detailed documentation we provided them in a separate report about those college's experiences. More BESS's will be needed with continued campus expansion under Title 24, and the findings presented from the campus site selection analysis will be used to help minimize installation costs, prevent implementation delays, and provide value to the University's maturing and decarbonizing power system.

Future Work

The report that will be presented to our client is separate from this one. In that report, detailed descriptions of BESS applications, commercially available control technologies, further examples of college campus BESS, and relevant electrical and fire codes are included. We hope that report provides useful information for UC Davis to make more informed decisions when it comes to future BESS installations.

In this paper, only transformers serving a single building were considered in the analysis. This was chosen as a decision variable due to minimizing complexity of electrical interconnection and the synchronization of demand data between different buildings over the studied one-year period. Another notable decision factor not thoroughly investigated in this report is the sizing of conductors and switchgears, and the impact of aging hardware on interconnection.

Once a site had been deemed suitable through analysis on AVEVA PI Vision, it would prove beneficial to connect a logger to the physical transformer to corroborate historical demand trend data. This logger should run continuously through at least one summer and for up to 18 months to best capture relevant demand information. Additionally, before anything is decisively selected, it is vital that building managers and relevant staff are incorporated into the process. Many of the tools utilized in determining site characteristics like physical space and infrastructure are static or require manual updating. To ensure just and accurate decision making, corroborating virtual data, and valuing the perspective of building managers and their staff is crucial.

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Appendix

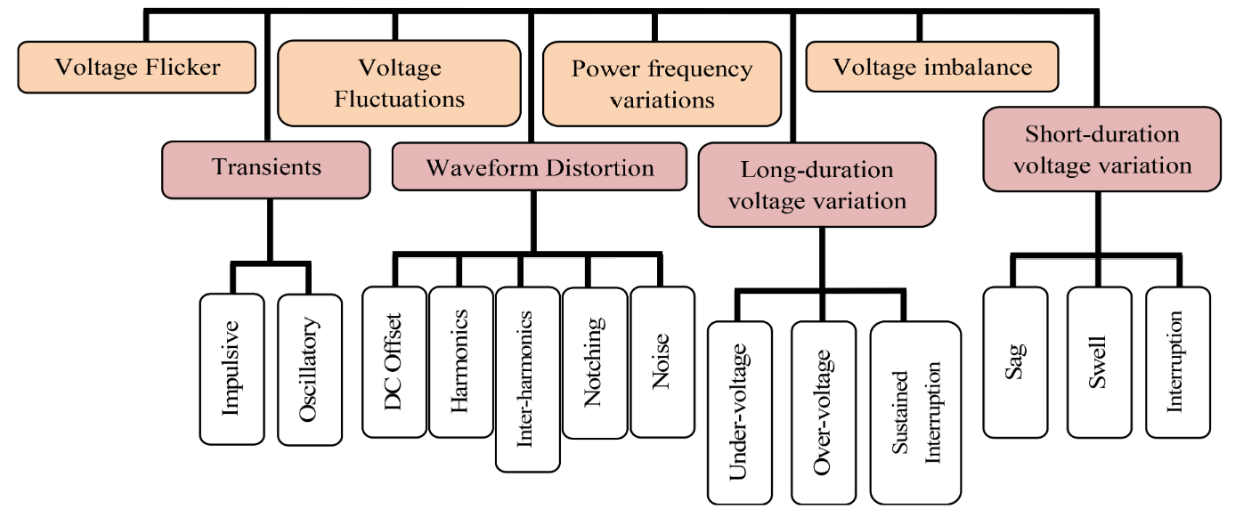
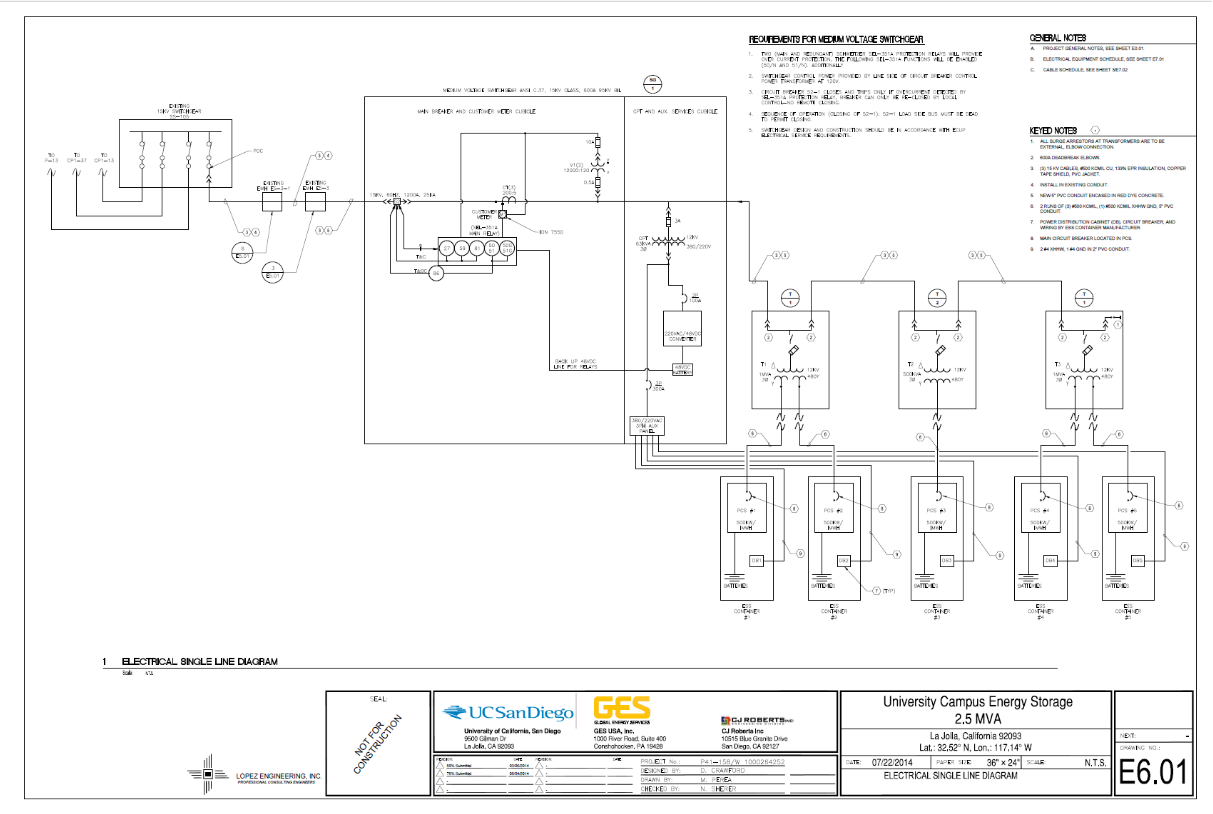


Figure 5. Classification of power quality issues [4]

Table 1. Description of most frequent power quality issue characterizations [4]			
Power quality issue	**Characteristics**	**Causes**	**Effects**
Voltage sag	● Magnitude: 0.1-0.9 V_{rms} ● Frequency: power frequency ● Duration: 0.5 cycles to 1 min	● Single line to ground faults ● Connection of heavy loads ● EVs ● Motor starting	● Protection malfunction ● Loss of production ● Malfunction of some controllers
Voltage swell	● Magnitude: > V_{rms} ● Frequency: power frequency ● Duration: 1 cycle to few seconds	● Large load switching ● Faults ● EVs ● Badly regulated transformer ● Capacitor switching	● Protection malfunction ● Stress on computers and home appliances
Short interruptions	● Duration: few milliseconds to two seconds	● Temporary faults	● Loss of production ● Malfunction of fire alarms
Long interruptions	● Duration: > 2 seconds	● Faults ● Failure of protection	● Loss of production

		devices	
Voltage imbalance	● Difference in three phase amplitude and/or phase angles	● Single phase load ● Single phasing	● Heating of induction motors
Harmonics	● Frequency: multiple of power frequency	● Inverter-based distributed generation ● Nonlinear loads (rectifiers in EV chargers)	● Increased losses ● Poor power factor ● Electromagnetic interferences

Figure 6. Aerial View of UCSD BESS ("Advanced Energy Storage System") and Surrounding Utilities [8]



REQUIREMENTS FOR MEDIUM VOLTAGE SWITCHGEAR

1. TWO (MAIN AND REDUNDANT) SCHWEITZER SEL-351A PROTECTION RELAYS WILL PROVIDE OVER CURRENT PROTECTION. THE FOLLOWING SEL-351A FUNCTIONS WILL BE ENABLED (50/N AND 51/N). ADDITIONALLY
2. SWITCHGEAR CONTROL POWER PROVIDED BY LINE SIDE OF CIRCUIT BREAKER CONTROL POWER TRANSFORMER AT 120V.
3. CIRCUIT BREAKER 52-1 CLOSES AND TRIPS ONLY IF OVERCURRENT DETECTED BY SEL-351A PROTECTION RELAY. BREAKER CAN ONLY BE RE-CLOSED BY LOCAL CONTROL-NO REMOTE CLOSING.
4. SEQUENCE OF OPERATION (CLOSING OF 52-1): 52-1 LOAD SIDE BUS MUST BE DEAD TO PERMIT CLOSING.
5. SWITCHGEAR DESIGN AND CONSTRUCTION SHOULD BE IN ACCORDANCE WITH ECUP ELECTRICAL SERVICE REQUIREMENTS.

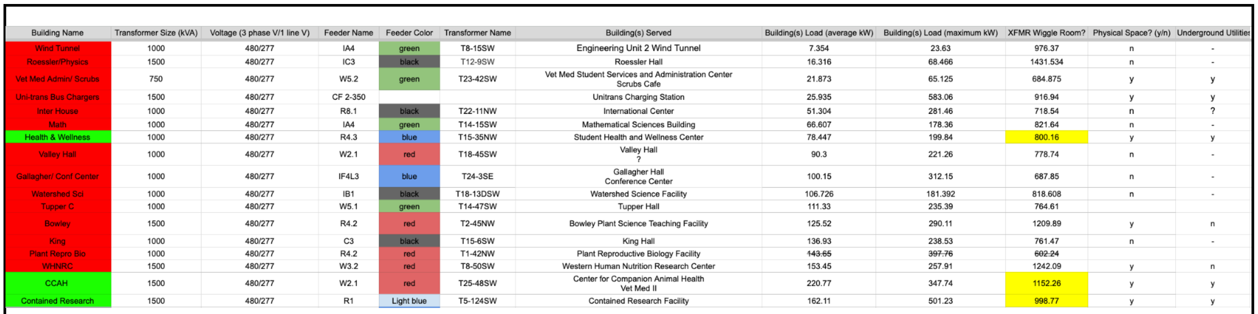
GENERAL NOTES

A. PROJECT GENERAL NOTES, SEE SHEET E0.01.
B. ELECTRICAL EQUIPMENT SCHEDULE, SEE SHEET E7.01
C. CABLE SCHEDULE, SEE SHEET 3/E7.02

KEYED NOTES

1. ALL SURGE ARRESTORS AT TRANSFORMERS ARE TO BE EXTERNAL, ELBOW CONNECTION.
2. 600A DEADBREAK ELBOWS.
3. (3) 15 KV CABLES, #500 KCMIL CU, 133% EPR INSULATION, COPPER TAPE SHIELD, PVC JACKET.
4. INSTALL IN EXISTING CONDUIT.
5. NEW 5" PVC CONDUIT ENCASED IN RED DYE CONCRETE.
6. 2 RUNS OF (3) #500 KCMIL, (1) #500 KCMIL XHHW GND, 5" PVC CONDUIT.
7. POWER DISTRIBUTION CABINET (DB), CIRCUIT BREAKER, AND WIRING BY ESS CONTAINER MANUFACTURER.
8. MAIN CIRCUIT BREAKER LOCATED IN PCS.
9. 2 #4 XHHW, 1 #4 GND IN 2" PVC CONDUIT.

Figure 7. UCSD BESS Interconnection Schematic



Building Name	Transformer Size (kVA)	Voltage (3 phase V/1 line V)	Feeder Name	Feeder Color	Transformer Name	Building(s) Served	Building(s) Load (average kW)	Building(s) Load (maximum kW)	XFMR Wiggle Room?	Physical Space? (y/n)	Underground Utilities
Wind Tunnel	1000	480/277	IA4	green	T8-15SW	Engineering Unit 2 Wind Tunnel	7.354	23.63	976.37	n	-
Roessler/Physics	1500	480/277	IC3	black	T12-9SW	Roessler Hall	16.316	68.466	1431.534	n	-
Vet Med Admin/ Scrubs	750	480/277	W5.2	green	T23-42SW	Vet Med Student Services and Administration Center Scrubs Cafe	21.873	65.125	684.875	y	y
Uni-trans Bus Chargers	1500	480/277	CF 2-350			Unitrans Charging Station	25.935	583.06	916.94	y	y
Inter House	1000	480/277	R8.1	black	T22-11NW	International Center	51.304	281.46	718.54	n	?
Math	1000	480/277	IA4	green	T14-15SW	Mathematical Sciences Building	66.607	178.36	821.64	n	-
Health & Wellness	1000	480/277	R4.3	blue	T15-35NW	Student Health and Wellness Center	78.447	199.84	800.16	y	y
Valley Hall	1000	480/277	W2.1	red	T18-45SW	Valley Hall ?	90.3	221.26	778.74	n	-
Gallagher/ Conf Center	1000	480/277	IF4L3	blue	T24-3SE	Gallagher Hall Conference Center	100.15	312.15	687.85	n	-
Watershed Sci	1000	480/277	IB1	black	T18-13DSW	Watershed Science Facility	106.726	181.392	818.608	n	-
Tupper C	1000	480/277	W5.1	green	T14-47SW	Tupper Hall	111.33	235.39	764.61		
Bowley	1500	480/277	R4.2	red	T2-45NW	Bowley Plant Science Teaching Facility	125.52	290.11	1209.89	y	n
King	1000	480/277	C3	black	T15-6SW	King Hall	136.93	238.53	761.47	n	-
Plant Repro Bio	1000	480/277	R4.2	red	T1-42NW	Plant Reproductive Biology Facility	~~143.65~~	~~397.76~~	~~602.24~~		
WHNRC	1500	480/277	W3.2	red	T8-50SW	Western Human Nutrition Research Center	153.45	257.91	1242.09	y	n
CCAH	1500	480/277	W2.1	red	T25-48SW	Center for Companion Animal Health Vet Med II	220.77	347.74	1152.26	y	y
Contained Research	1500	480/277	R1	Light blue	T5-124SW	Contained Research Facility	162.11	501.23	998.77	y	y

Figure 8. Screenshot from Excel Spreadsheet

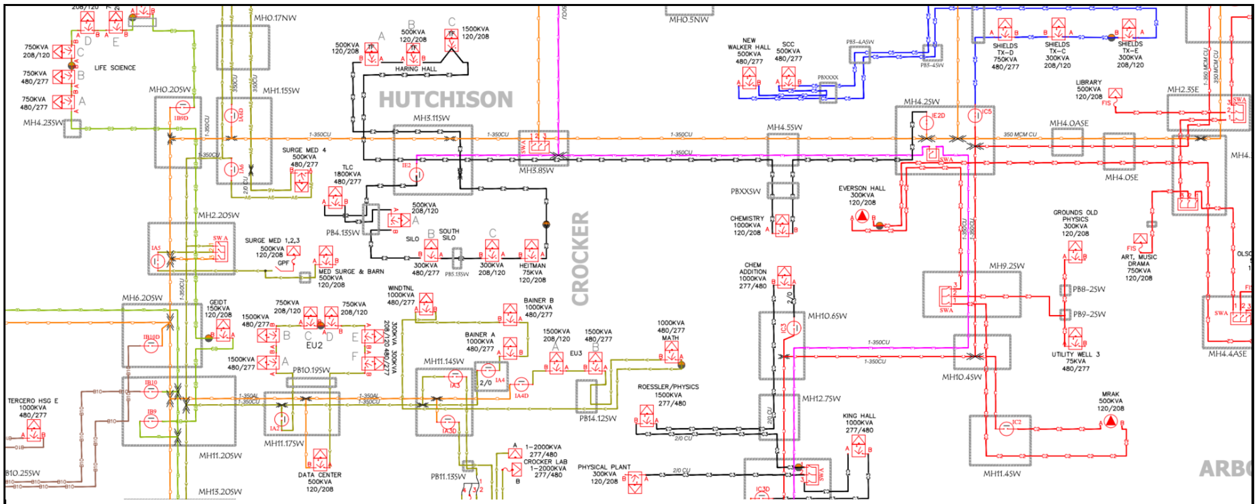


Figure 9. Partial Screenshot of Campus Single Line Diagram

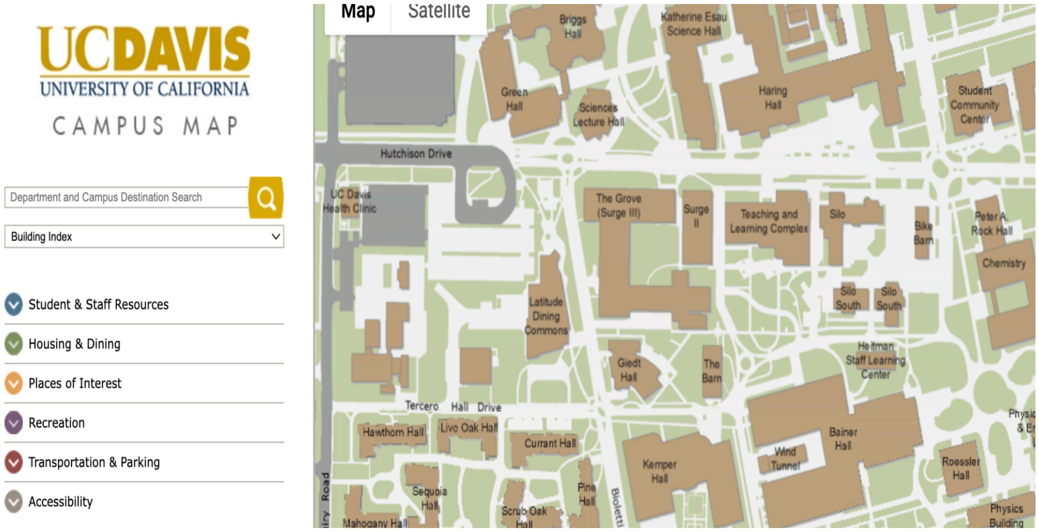


Figure 10. UC Davis Campus Map

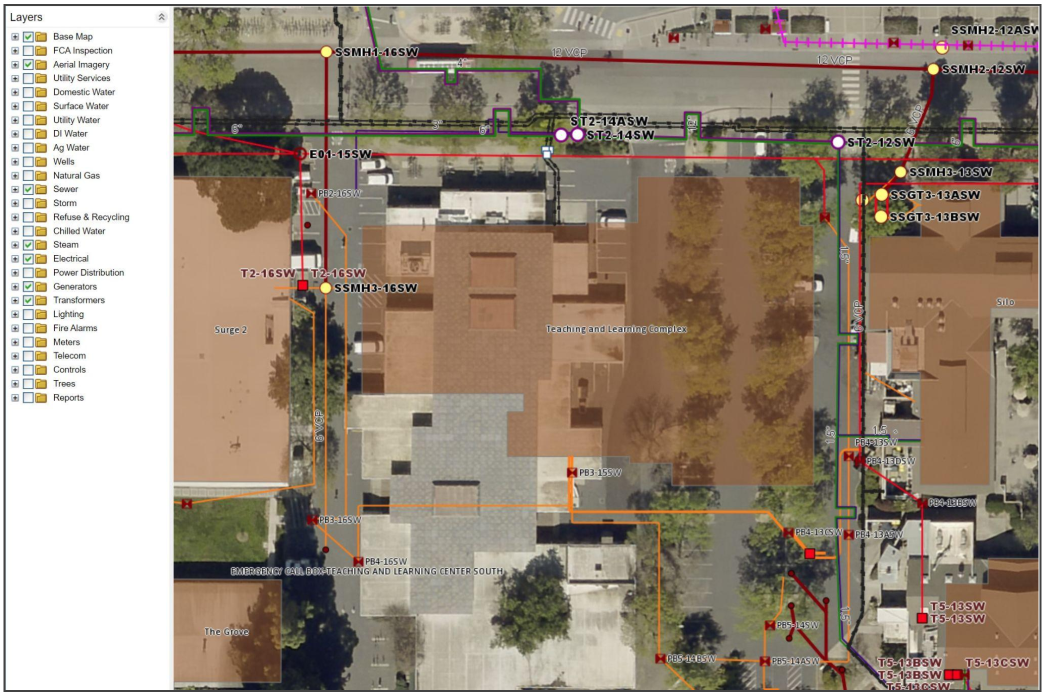
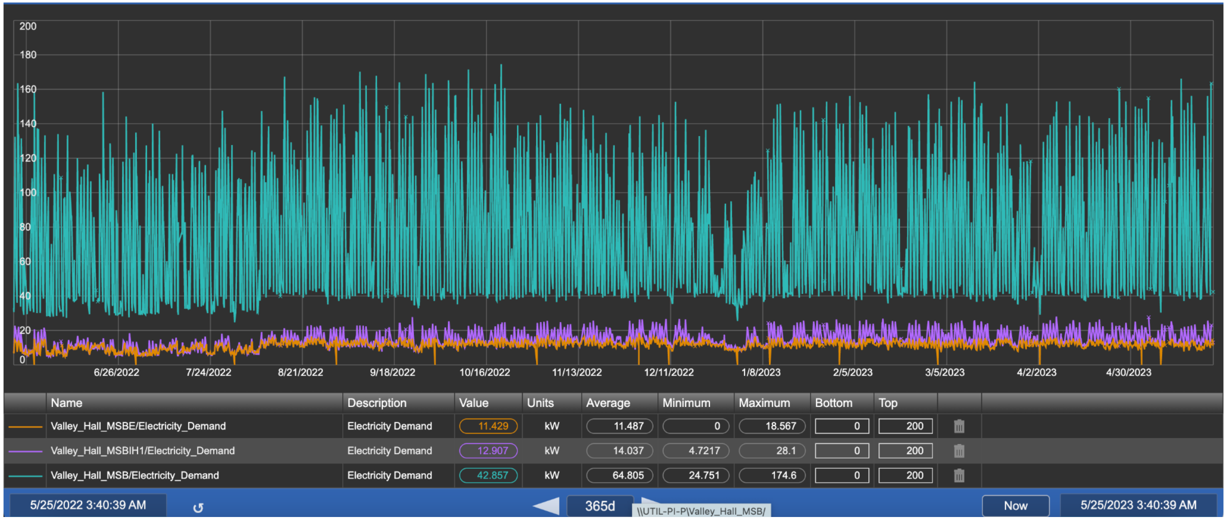
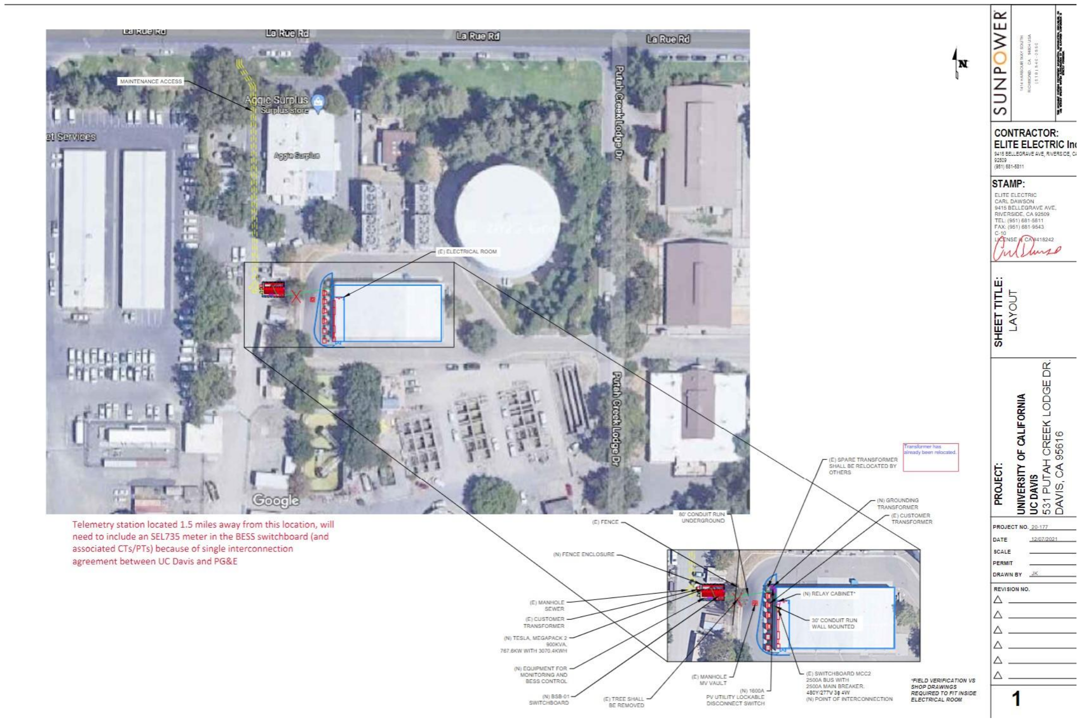


Figure 11. Building View from Facilities Map



	Name	Description	Value	Units	Average	Minimum	Maximum	Bottom	Top
—	Valley_Hall_MSBE/Electricity_Demand	Electricity Demand	11.429	kW	11.487	0	18.567	0	200
—	Valley_Hall_MSBIH1/Electricity_Demand	Electricity Demand	12.907	kW	14.037	4.7217	28.1	0	200
—	Valley_Hall_MSB/Electricity_Demand	Electricity Demand	42.857	kW	64.805	24.751	174.6	0	200

Figure 12. Example Electrical Demand Trend on AVEVA PI Vision



Telemetry station located 1.5 miles away from this location, will need to include an SEL735 meter in the BESS switchboard (and associated CTs/PTs) because of single interconnection agreement between UC Davis and PG&E

Figure 13. Sunpower Feed Mill BESS Diagram

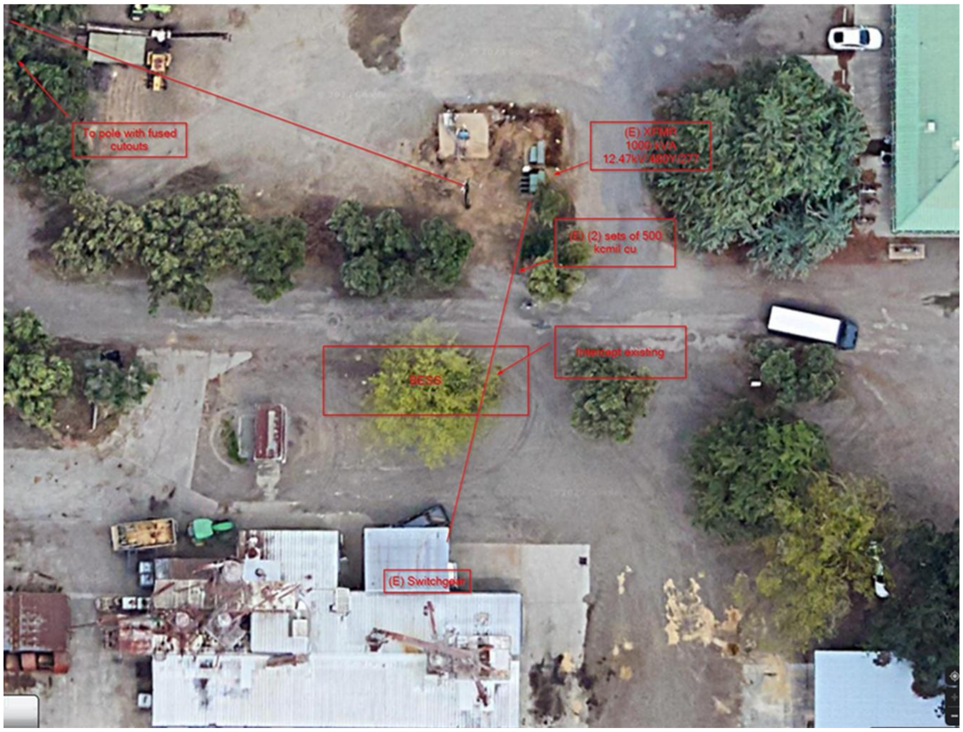


Figure 14. Annotated Aerial View of Feel Mill Site