Solar + Storage for Resiliency

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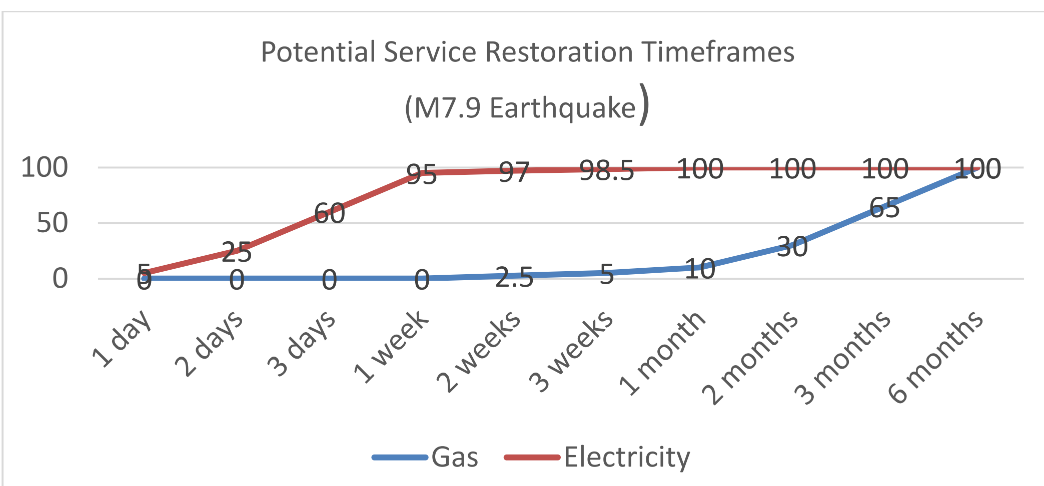
ABSTRACT

The City and County of San Francisco's Solar+Storage for Resiliency (SSR) project has developed a roadmap to expand the solar market by serving as a national model for implementing solar and energy storage as a disaster preparedness strategy. The project team has worked closely with local stakeholders, utilities, and operators of San Francisco's critical facilities, including: a fire station, a police station, municipally and privately owned shelters, health centers, emergency assembly areas, and kitchens. Project partners have identified and selected twelve disaster preparedness zones and performed preliminary design on each. In some zones, the critical loads in several co-located buildings are grouped to form a microgrid and share power in the event of an extended outage. The team has developed potential financial and ownership models to build and maintain the systems, and has produced four case studies of specific microgrid projects planned for financing and construction. The project is addressing regulatory, financial, and technical barriers and has created a road map for deploying Solar + Storage for resilience both locally and nationally.

The Problem

According to the San Francisco Lifelines Council (SFLC, 2014), a major earthquake in the Bay Area would cause a power outage that could take up to three weeks for a full recovery of electric power (Figure1). The San Francisco Department of Emergency Management's website asks citizens to expect at least three days of no outside assistance at all (www.SF72,2016).

Figure 1: Service Restoration Timeframes (percent of recovery)



Source: San Francisco Lifelines Council: percentage of restoration over time.

A major Bay Area wide event could mean no help arrives for a week or more leaving a gap of at least several days. This project considered several design problems including:

- Hospitals and fire stations have generators, however, they have at most three days of fuel to operate their critical loads. This means if there are no fuel deliveries for more than three days, these facilities will stop functioning. Adding fuel tanks is not a good solution because: (1) fuel filled storage tanks are a hazard in themselves during an earthquake, (2) they require considerable space that is difficult to obtain in a dense urban environment, and (3) they can be difficult to permit.
- While some critical facilities have generators, many do not. During a major disaster, additional facilities need to operate 24 hours per day for sheltering, feeding, field medical clinics, operations staging, and meeting other needs such as caring for people who, prior to the event, were already sick, disabled, emotionally stressed, etc.
- Citizens, and especially vulnerable populations, need electric power for charging wheel chair batteries, oxygen generators, home dialysis machines, and phones for communicating with loved ones which helps to manage stress among the affected, in turn reducing the pressure on police, fire, and medical personnel.

A Solution

Solar photovoltaic (PV) panels combined with energy storage, batteries, can provide limited, yet reliable power. The advantages of using solar with storage for emergency power system are many, including:

- Backup generators need maintenance and monthly testing while solar with batteries require minimal maintenance.
- Diesel or gas powered generators contribute to poor air quality during monthly testing as well as during the disaster, while solar with battery power does not.
- Backup generators are only used during an emergency, while a solar with storage solution provides daily benefits in bill reduction and peak load management.

There is an additional benefit of using a solar and storage solution: there are already 13 MW of PV capacity in 6000 installations spread over almost every neighborhood in the city. These systems can be adapted, at low cost, to continue operating during a power outage.

The pairing of storage with solar has additional resilience benefits by reducing the likelihood of power outages from grid instability. The emergence of solar PV has created a statewide challenge, and potentially a local challenge. As PV power wains each afternoon, electric utilities are forced to ramp up quickly to meet the evening peak load. With more PV, the ramp starts from a deeper point and is made steeper. Adding storage can address this problem. The storage can absorb the solar power, reducing the depth of the ramp, and discharge later in the day to alleviate the steepness of the ramp. This means that if the City is going to meet its carbon emissions goals and its renewable energy goals, it will need to promote energy storage just as it promotes solar PV.

This project, Solar + Energy Storage for Resilience, funded under the US Department of Energy (USDOE) Solar Market Pathways Program, identified almost fifty zones for development of solar PV with energy storage to provide power for critical loads during an extended power outage. Each zone is comprised of up to three facilities identified as part of the City's disaster response plan. Where possible, the project opted to target co-located facilities because of the benefit of potential synergy of operations among different facilities, as well as the possibility of developing a shared microgrid among the group of facilities. For example, one zone has a community center, a school, and a church. The church already has solar on its roof while the school roof is shaded and the community center has a weak roof. The church parking lot is also the best option for placing the battery. In this case, connecting the three facilities with a wire into one microgrid, utilizing the existing solar system, may be the fastest and cheapest solution to provide all three with power. Other criteria for selecting facilities are addressed later.

The zones will not provide full power for the facilities, but are sized to meet critical loads, primarily minimal lighting, refrigeration for medicines, battery charging, and other communications.

The Methodology

There are multiple challenges addressed by this project: site identification, site selection, preliminary design, and approvals. The project is designed to address these issues through delivering preliminary designs for specific projects in San Francisco while delivering tools and methods for use by local governments across the United States. The project has multiple steps, some occurring in parallel.

1. Develop a team of experts and partners.
2. Develop a GIS based map of potential sites
3. Select twelve sites
4. Produce a sizing tool for loads, PV, and storage systems
5. Perform a preliminary design for each system
6. Link financing and ownership options for each system
7. Develop a plan for utilizing existing solar systems
8. Develop a roll out plan to implement the projects

Other project tasks include reviewing municipal disaster preparedness plans that mention solar, storage, or micro-grids (very few); addressing regulatory and/or legal barriers; and share information and best practices with other awardees of the Solar Market Pathways program.

The Partners

The Solar + Storage project has engaged a diverse set of partners able to support the project in specific issue areas including finance, technical evaluation, and utility integration**.** The partners fall into several categories:

Consultants: The primary technical consultant is ARUP with Celtic Energy and Strategen as subcontractors for performing the technical work on the map, site selection, preliminary design, and financing.

Academia: Lawrence Berkeley National Lab is providing advice, review and organizing a technical workshop to develop a plan for utilizing the existing PV systems. Sandia National Lab is also providing review. USDOE has provided additional technical assistance from the National Renewable Energy Lab for review of the load sizing tool.

Non-Governmental: Rocky Mountain Institute (RMI) brought four members of the team to an E-Lab Accelerator to help the team think through the project process. The Clean Coalition is providing analysis of the PV and energy storage needs for the distribution system in the fast developing south east sector of the city. Renewable Funding is providing finance expertise.

Utility: Pacific Gas & Electric is providing technical expertise and information about the distribution system and tariffs. The San Francisco Public Utilities Commission, which provides electricity only to municipal and school district buildings, is providing metering data and review.

City Agencies: Several additional agencies of the City and County of San Francisco include the Department of Emergency Management, the Public Health Department, the Planning Department, and the City Administrator's Office (CAO) that includes the Chief Resilience Officer. They bring the knowledge of the departments and their facilities, perspective on goals and support for the project goals and objectives.

Citizens: Citizens are engaged through existing partnerships with the City. The Neighborhood Emergency Response Teams are trained and receive organizational support by the Fire Department. The Neighborhood Empowerment Network is a network of neighborhood leaders all over the city and is supported by the CAO. Citizens provide critical feedback on project design and operation plans as well as implementation during a disaster.

Mapping the Opportunities

The San Francisco Department of Emergency Management (SFDEM) has identified the buildings to be included in the study. The buildings nominated by SFDEM are locations crucial to the City's emergency disaster relief strategy and include: police stations, fire stations, medical facilities, disaster relief coordination centers, shelters (e.g. recreation centers), kitchens (e.g. Salvation Army), and public assembly buildings. Additional risk areas have been identified in relation to a number of disaster categories. Applicable hazards are specific to the location. The following disaster factors were considered: earthquake faults, liquefaction zones, landslide zones, tsunami zones, reservoir failure inundation zones, and heat vulnerability.

The extent of affected land for each factor was transposed onto an interactive map to provide an overview of which areas are vulnerable to each disaster situation. Additional data was mapped including an earthquake rating of some buildings, parcel boundaries, and the borders of districts of the Board of Supervisors. A GIS spatial data viewer created an interactive map that allows users to review the mapping data available for the project (Figure 2). The red circles on the map indicate locations were first indicated as potential locations, largely because of the proximity of two or more emergency facilities in close proximity to each other. This viewer is available on the Web and can be accessed by anyone given security authorization[1].

[1] http://sfenvironment.org/article/renewable-energy-solar/solar-and-energy-storage-for-resiliency

Figure 2: Interactive Map and Potential Sites

Source: ARUP

Site Selection

The map was used to identify appropriate co-located facilities. Post-disaster, many people are driven from their homes and large open spaces are needed to provide services and accommodate large numbers of people. Co-located facilities delivering other services is an advantage during disaster recovery because:

- reduces people moving from one location to another to obtain needed services,
- creates redundancy in the case that one facility collapses the other(s) may be able to continue operating
- it may reduce the cost of providing solar electric service to each facility separately
- one building may not be able to house PV and/or batteries and may need to draw from, or lend to, another facility.

Sites have been selected via a multi-stage process:

1. Using the map, the project team performed a first screen of potential facilities and identified almost 50 sites (Figure 2), screening out facilities with poor earthquake ratings or in inundation zones, liquefaction zones, or had other known problems.
2. A meeting was held with the manager of the Neighborhood Empowerment Network and other City project staff with extensive knowledge of the city's neighborhoods, organizations, and leaders in many of the potential areas.
3. Staff met with each member of the Board of Supervisors or their staff to select among the options in their particular district. Supervisors are most knowledgeable about the needs of their district and provided valuable additional information about the sites, provided warnings about potentially complicating social issues, and provided contacts for individuals they wanted to be certain are included in the zone development process.

4. Staff contacted City departments about the identified buildings to verify their viability and identify any problems with the selected facilities. In retrospect, this step could have been taken sooner, first screening out municipal buildings known to have problems or near term renovation plans, as well as lining up top management support and identifying points of contact to arrange site visits.

5. Staff met with private sector building owners and community representatives to solicit buy-in and identify any problems with the selected facilities.

Load Sizing Tool

The preliminary design process started with the development of a tool that would help calculate the size of the PV and storage system. To develop the tool, ARUP started with site investigations arranged by the SFDEM. ARUP toured an example facility of each type. Site visits were conducted with both an onsite facilities manager/engineer, as well as the manager of the facility that would be on-duty during emergency and disaster operation. On the site visit, the team assessed the disaster service intent of the facility, the electrical needs during an emergency, number of occupants expected, hours of operation and expected period of use. It also identified potential space for solar panels, looked at the structural integrity of the roof, noted the condition of the roof, looked at adjacent open space (e.g. parking lots), looked at the existing electrical system, and assessed any existing emergency back-up generators.

In order to determine the building's use energy during a disaster, it is important to understand not just what the loads are, but when they occur, how many people are expected, what electrical appliances they expect to use and for what time periods. Though interval data was not available, load profiles were developed using monthly data and using load estimations and time of use predictions for normal operation because (Figure 3). If this data is not available

Figure 3: Sample of load estimating tool

Time	Lighting	Computers	Plug loads	Server / Telecom	Total (W)
0:00	320		912	350	1,582
1:00	320		912	350	1,582
2:00	320		912	350	1,582
3:00	320		912	350	1,582
4:00	320		912	350	1,582
5:00	320		912	350	1,582
6:00	320	180	912	350	1,762
7:00	320	180	912	350	1,762
8:00	320	180	4,227	350	5,077
9:00	320	180	4,227	350	5,077
10:00	320	180	4,227	350	5,077
11:00	320	180	4,227	350	5,077
12:00	320	180	4,227	350	5,077
13:00	320	180	4,227	350	5,077
14:00	3,440	180	4,227	350	8,197
15:00	3,440	180	4,227	350	8,197
16:00	3,440	180	4,227	350	8,197
17:00	3,440	180	4,227	350	8,197
18:00	3,440		4,227	350	8,017
19:00	3,440		4,227	350	8,017
20:00	3,440		4,227	350	8,017
21:00	320		912	350	1,582
22:00	320		912	350	1,582
23:00	320		912	350	1,582

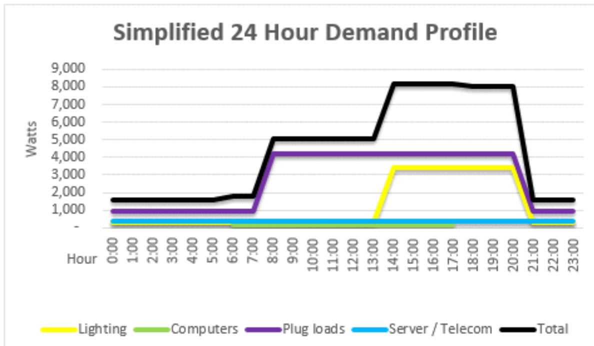
Source: Arup

then the load estimations and demand profile will need to be built up. This is done by inspecting the site, documenting the electrical equipment and determining the expected usage periods of the equipment. This involves meeting with the facility operator and querying how the building will be used. The loads are then allocated across timeslots and the total per hour is determined.

The load sizing tool allows the user to build a customized disaster load profile, calculating the amount of lighting needed, number of cell phones to charge daily, the number of computers, and other batteries and electric appliances to be supported. It calculates the average hourly emergency load (Figure 4), the amount of PV and energy storage needed to meet the load, and builds in assumptions about insolation and system efficiency. Visit the project website[2].

The load table can then be presented as a simple demand curve as shown below.

Figure 4: Simplified Demand Profile

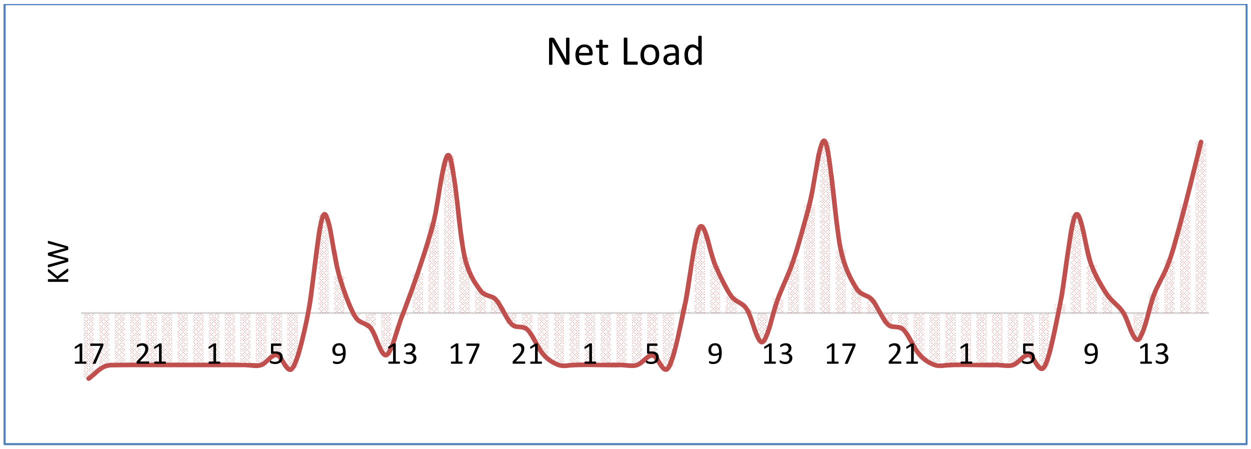


Source: ARUP

After estimating the loads for each building, the solar systems were sized based on the estimated power needs and oversized to compensate for reduced insolation. GIS rooftop area measurements and nearby open areas along with irradiation data for the closest location available were used to estimate upper limit of the array output. Then electrical net load profiles were calculated (Figure 5) over a number of days with an expectation of reduced output from weather

[2] http://sfenvironment.org/article/renewable-energy-solar/solar-and-energy-storage-for-resiliency

Figure 5: Net Load



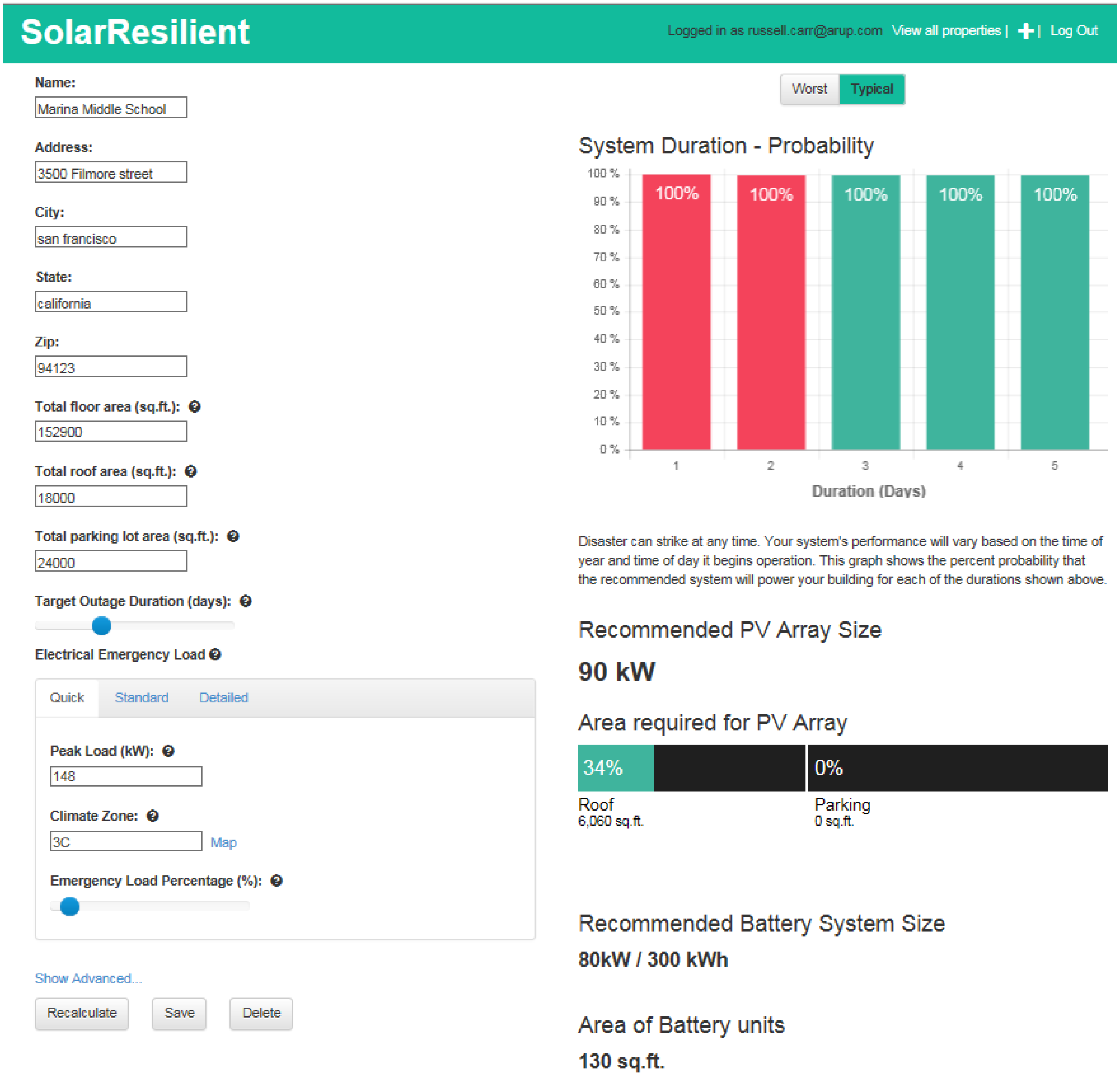
Source: ARUP

or smoke and debris from the event. Once the expected power outage periods were established the required battery storage was sized.

The energy storage sizing tool provides a preliminary estimate of kW/kWh requirement to maintain the resilient solar plus storage solutions. The system sizing tool was reviewed by NREL and the technical partners.

There are three ways in which a buildings energy load can be estimated in order to allow quick assessments to be made or deeper assessments to match the user's needs. A screen shot of the tool performing a 'Quick' assessment for a site is presented below (Figure 6).

Figure 6: SSR Sizing Tool



Source: ARUP

The load sizing tool offers three methods of developing an estimate:

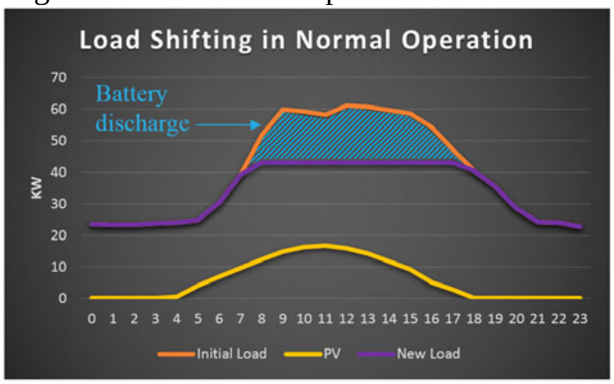
1. ‘Quick’ Enter the buildings peak load, found on the billing data and climate zone and the tool will estimate the required emergency load based on a database of pre-loaded buildings. This method often produces larger size systems than the other methods.
2. ‘Standard’ Upload the buildings annual hourly energy data and select the percentage of emergency load.

3. ‘Detailed’ Build up the exact loads of the building as described earlier in this section. This method better reflects the operation of the building and calculates a more accurate system size.

Preliminary Design

Unlike traditional back up power systems, a resilient microgrid is designed to operate and provide benefits during all modes of operation. A smart microgrid is capable of managing supply and demand through day to day operation as well as in emergency situations. In normal operation (Figure 7), the system will utilize the power generated by the PV system to reduce the electricity imported from the utility grid.

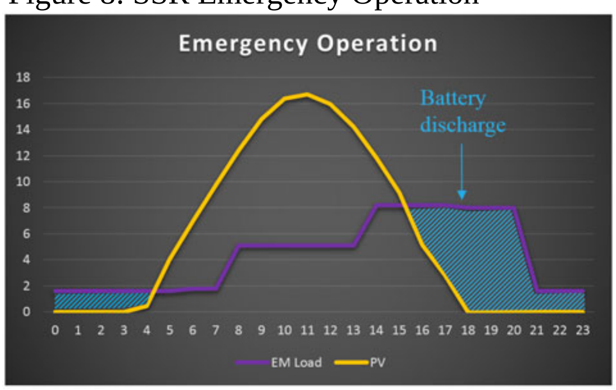
Figure 7: SSR Normal Operation



Source: ARUP

During an emergency (Figure 8) , the system will disconnect from the distribution system and operate independently. The PV system is sized to produce excess power during the day, which will be stored and used primarily in the evening hours with some loads lasting through the night and into the following solar day.

Figure 8: SSR Emergency Operation



Source: ARUP

The design process consists of three parts: preliminary engineering, community input, and final design. In preliminary engineering, each building’s loads are sized based on a site visit and meeting with the on-site staff and staff responsible for operations during the emergency. Using utility data, the PV and storage needs are calculated using the sizing tool. If a building has insufficient space for either the PV or the storage, then one of the other facilities will be identified for placement of the needed asset.

In these cases, there are two options for connecting the facilities into a multiple facility microgrid: utilize the existing utility distribution wire or run a separate wire. In cases where running a separate wire would be across a playground or ball field the cost will be low. However, some San Francisco neighborhoods are in dense areas with little open space. Running a wire under the streets where there may exist a maze of current and legacy pipes can cause trenching costs to reach upwards of $2,000 per linear foot.

Utilizing the existing distribution system is not simple. First, PV systems are designed to disconnect during a power outage is to avoid having any power feed on the line while workers are attempting a repair. Therefore, that portion of the line would have to be sectioned off with a control switch to avoid the hazard. Further, if other non-emergency facilities are on the same section of the line, they would have to be individually disconnected from the system to avoid draining power from the critical loads.

Fortunately, of the twelve sites selected in San Francisco, only three appear to have need of running a separate wire and only one is in a very dense area. While a separate wire poses an additional cost to the project, it is not insurmountable given the usefulness of the system in a disaster.

Sample Preliminary Design

Supervisor Mark Farrell is the elected representative of District 2 with eleven distinct neighborhoods, a population of 68,000, and a liquefaction zone. The Supervisor selected the Marina Middle School as the site because it was recently seismically upgraded, is identified as an emergency shelter, has a very large ball field designated as a NERT staging area, and is on the edge of the liquefaction zone meaning there are likely to be many people coming to the school as a safe area.

The building has an area of 152,900 square feet and consumes around 2,150 kWhrs of electricity per day. During a disaster, the school can shelter 132 people for sleeping (for the duration of the power outage) and an additional 942 people for short term emergency evacuation (estimated 8 hours). A needs assessment included a table (Figure 9) to identify each space planned for use.

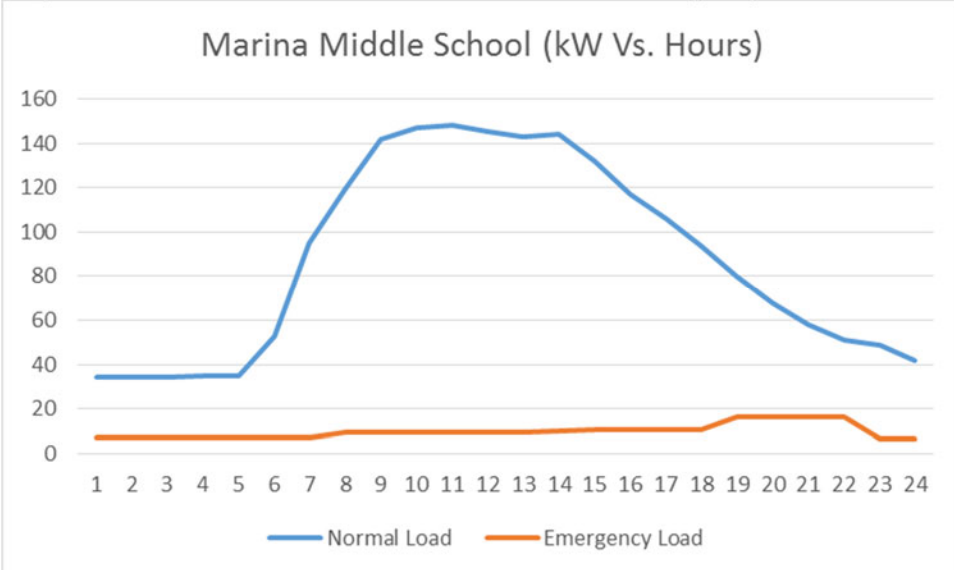
Table 1: Spaces and Uses in Marina Middle School

		Space Use							Occupancy	
Interior Spaces	**Area (SF)**	**Dormitory**	**Dining**	**Office**	**Interview**	**DHS**	**Kids area**	**Rec/Meeting**	**Sleeping capacity**	**Evacuation capacity**
Auditorium	6540									327
Cafeteria	3724		x							186
Office	1231			x	x	x				
Gym	8582	x							132	429
Conference room	1321			x	x	x	x	x		
Room 104	1292		x		x	x	x	x		
Room 171	1200		x		x	x				
Total	23890								132	942

Source: ARUP

The emergency load was calculated at approximately 11% of the school’s normal daily load of 230kWhrs. A battery storage system of 50kW capacity and 200kWhr of discharge capability would be adequate to support the building for a three-day power outage. The sizing tools ‘Quick’ calculation method takes the building’s peak load and scales this profile to create an emergency profile. The estimated electricity load profile for emergency conditions is shown below (Figure 9).

Figure 9: School Load Profiles for Normal and Emergency Conditions



Source: ARUP

The school has 18,000 square feet of roof space and 24,000 square feet of parking space for potential solar installation. The required space for this PV installation is under 4,200 square feet. A 60kW PV system would provide ~20% of the school's annual energy needs.

Community Participation

When a widespread disaster hits, the streets are likely to become blocked by fallen buildings, poles, power lines and people, forcing first responders to address problems where they are at that. Therefore, for some neighborhoods, it is possible that no first responders will arrive immediately. It is likely that neighborhood residents and business owners will take charge and, while the systems should operate automatically with easy to understand manuals, good preparation dictates training nearby residents and site staff on how to utilize the systems. The Neighborhood Emergency Response Teams will also be trained to operate these systems.

To ensure neighborhood support, once a set of design options are developed, community buy-in and input is needed on the system, from the design options through to the training of local volunteers how to operate and maintain the equipment during the disaster. Where the community should be involved in the decisions are in the placement of the equipment, the assumptions about the loads needed to be served, and about the ownership and maintenance contracts needed to be certain these assets will be serviceable at the moment that disaster strikes.

In San Francisco, the Neighborhood Empowerment Network links the project to the community. Some neighborhoods already have developed a disaster preparation plan and have an understanding of the services they need to provide, the number of people expected to be served, and have identified sites where electric power is needed. Once each preliminary design is completed, the team will meet with that neighborhood's leadership to obtain their input, finalize the preliminary design and discuss a plan for construction, maintenance, and operation.

Next Steps

Several steps written in the Abstract have yet to be performed; therefore, at this writing no further detail can be presented. The remaining steps are: completing the preliminary site designs, feedback from the community, developing the financing and ownership options and the strategies for utilizing existing PV systems. By the time of the presentation at the Summer Study, the implementation, or roll out plan, will also be completed. The results will be incorporated into a final version of this paper available on the project website: http://sfenvironment.org/article/renewable-energy-solar/solar-and-energy-storage-for-resiliency

References

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