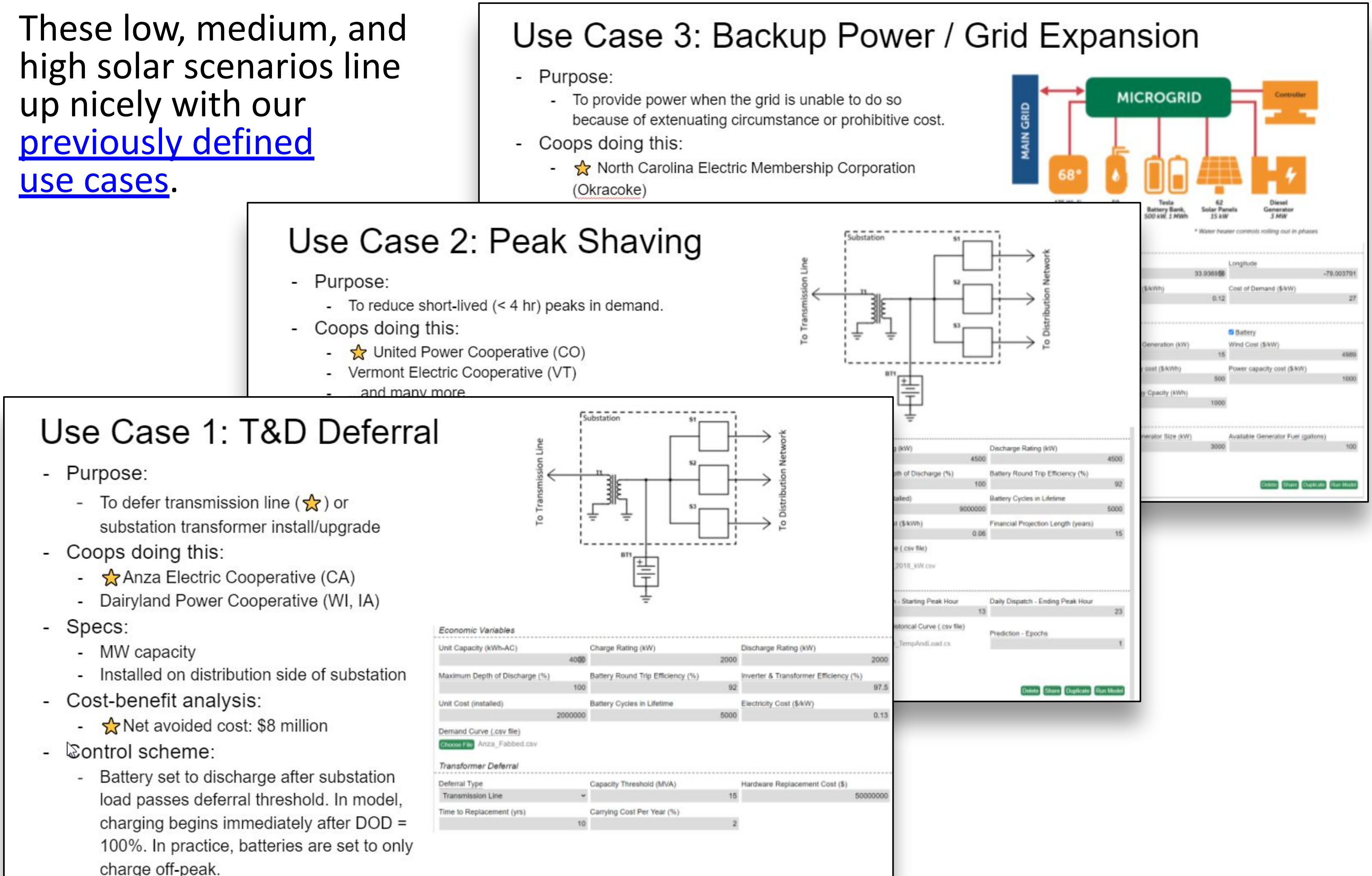
Real Analysis With SPADES

- Problem: How would inverter hacks impact distribution utilities nationally?
- Approach: Develop realistic attack scenarios for key circuits.
  1. Determine reasonable residential PV deployments including centralized and decentralized elements
     - Lots of solar: California
     - Modest solar: Colorado
     - Very little solar: North Carolina
  2. Develop realistic battery deployment/control scenarios that include centralized and decentralized elements:
     - T&D deferral: California
     - Peak shaving: Colorado
     - Backup: North Carolina
  3. Generate reasonable load curves.
  4. Apply to the ieee37 and iowa240 circuits.
  5. Quantify impacts in terms of equipment costs, lost service, time for restoration.
- Previous Work: see SPADES Reqs and Specs for detailed use case definitions.

Real Analysis With SPADES

These low, medium, and high solar scenarios line up nicely with our [previously defined use cases](#).

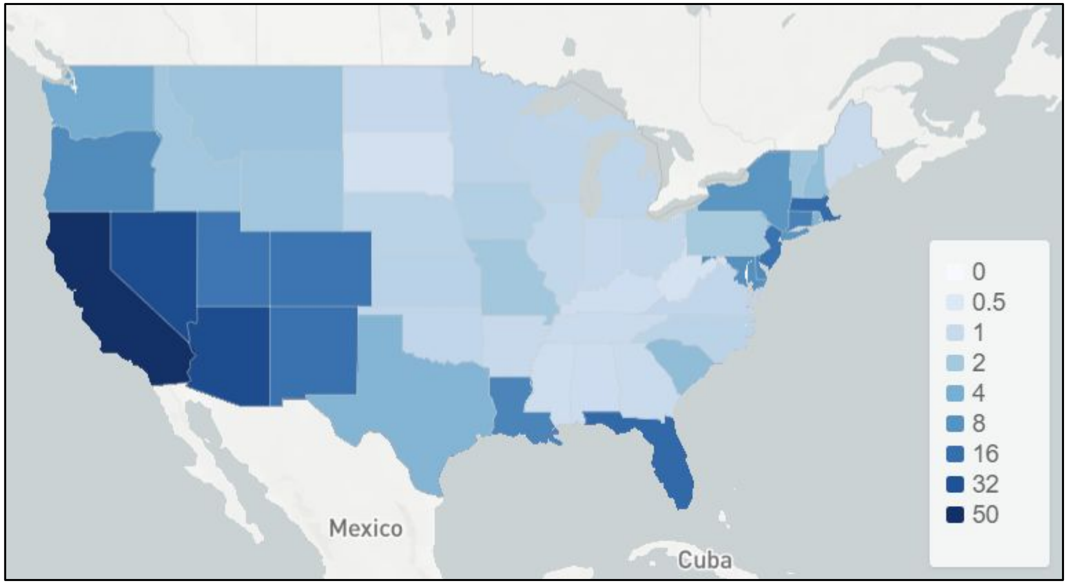


Obtaining Typical PV Penetration Levels

- DeepSolar provides a deep learning model that detects solar panel installations from satellite imagery, estimates sizing, and determine whether the use case is residential or non-residential.
- Results of a study using DeepSolar are provided in aggregate through this map-based visualization. (Zoom in for resolution down to the census tract.)
- Results from the published article can be used to infer approximate PV penetration based on the average insolation (and/or average electricity rates).

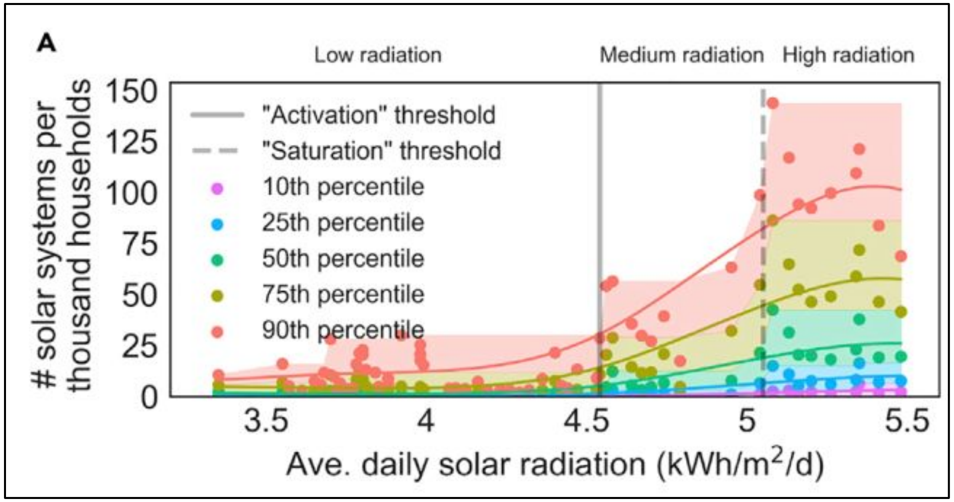
From the map:

- High insolation ->
  30 systems/1000 houses
- Medium insolation ->
  10 systems/1000 houses
- Low insolation ->
  2 systems/1000 houses

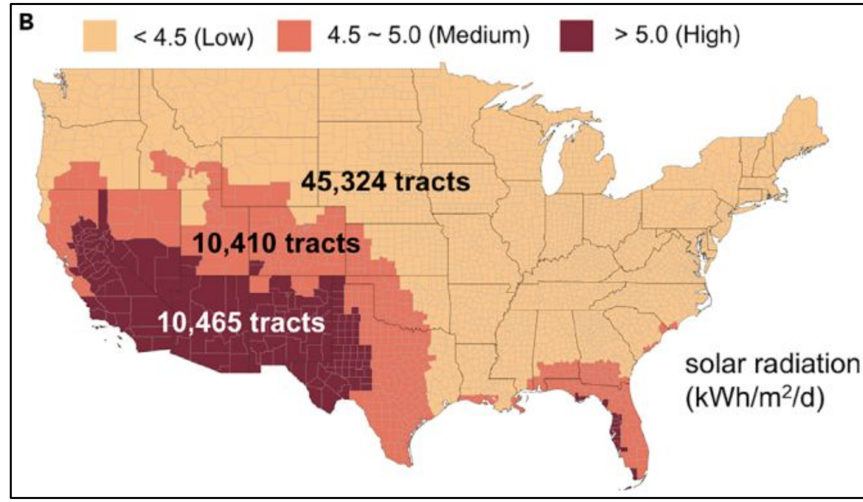


PV penetration factor for each state in the US in solar systems per 1000 households

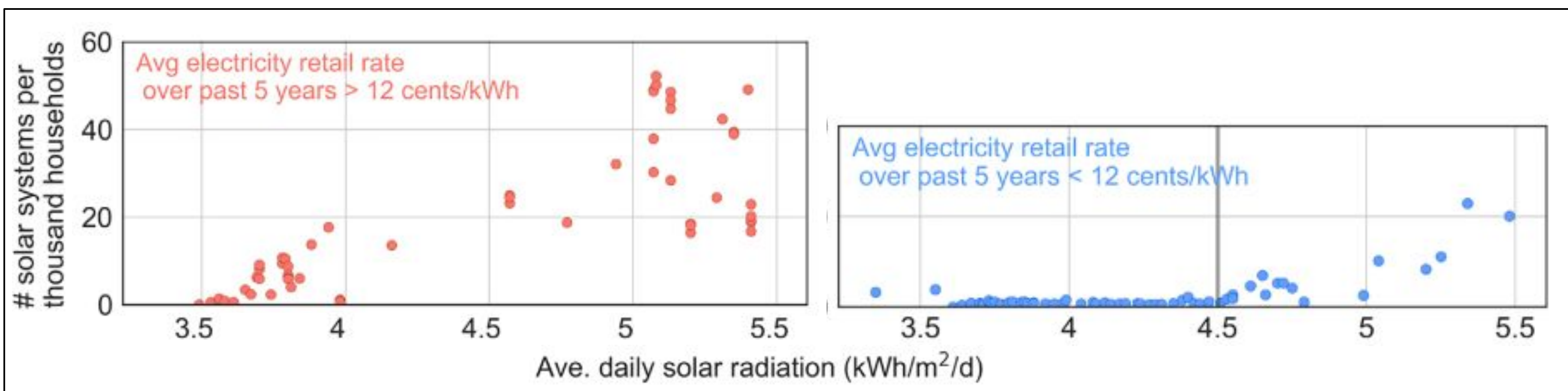
Obtaining Typical PV Penetration Levels



(A) Solar deployment density vs average insolation. Shaded areas represent the cumulative maximum of percentile scatters. We can use the 50th percentile value for high, medium, low insolation.



(B) US map colored according to the three levels of average solar radiation defined by the thresholds identified in (A) (high, medium, low). Census tracts are grouped according to 64 bins of solar radiation.



(C) Solar deployment density correlation with solar radiation, conditioned on the level of electricity retail rate.

Obtaining Typical PV Generation Data

PV Penetration can be combined with the average sizing of installations to generate PV power profiles.

- ASU's PySoda is great for this purpose.
  - Github: https://github.com/Ignacio-Losada/SoDa
  - Journal paper: SoDa
  - Output is in kW
- A 1-second solar generation profile was obtained for each size of PV installation modeled at the location.
  - Utility-scale installations were sized according to actual parameters.
  - Residential installations were sited and sized according to PV penetration and typical household demand.
  - All same-sized PV installations have the same generation profile.
- Apply additional variation as desired.
  - Apply rooftop PV sizing distribution?
  - Panel shading?
  - Panel cleanliness?
  - Distribution of efficiencies based on manufacturer market share ratios?

Identifying Appropriate BESS Design

Both utility-scale and distributed battery installations are represented.

- Utility-scale battery asset parameters are informed by actual installations but corrected for the test circuit size (ieee37 with aggregate loads of 2662 kVA)
- Distributed batteries are represented as solar-plus-storage installations.
  - Residential BESS are assumed to accompany 30% of rooftop PV installations
  - Assumed residential Batteries are Tesla Powerwall 2 at 5.8 kW / 13.5 kWh.
- The battery control approach for each use case is outlined in this document, jointly produced by LBL and NRECA.
- Battery controller parameters are specific to co-op installations.
  - T&D Deferral: Rated apparent power for the asset
  - Peak Shaving: Peak/Off-peak times
  - Microgrid: TBD

1) Deferral for a Small California Town

General scenario information

- Use Case: Transmission line deferral
- Lat, long: 33.560566, -116.672204
- State(s): California
- Countie(s): Riverside
- Peak demand: 15.6 MVA (summer); 11.8 MVA (winter)
- PV Penetration: 11.0%
- Circuit file: (temp) ieee37_LBL.dss (2500 kVA)

Existing PV installation information

- SunAnza (phase 1) - 1.4 MW
- SunAnza (phase 2) - 2 MW
  - Location: 33.557193, -116.642640
- ~1 MW of rooftop PV systems (as of 2018). This becomes 1.4 MW after correcting for the 38% increase in california residential PV from 2018 to 2021.
- With 6174 meters as of May 2021 and 11% PV penetration, the average rooftop installation is 2.1 kW.
- Average demand per meter during the peak is 2.5 kW.

The sprawling properties in Anza, CA tend to involve multiple buildings and often include livestock pens.

1) Deferral for a Small California Town

BESS installation information

- SunAnza 2020- 2 MW / 4 MWh
  - Location: 33.557193, -116.642640
  - Completed 2020 alongside phase 2 of PV install
- TBD - 2.5 MW / <unknown> MWh
- TBD - <unknown> MW / 18 MWh

Other information

- Sunset on July 23, 2017 occurs between 19:56 and 21:35.
- Electricity rate: $0.13 - $0.19 per kWh

Another home in Anza, CA. Large land tracts make ground-mount solar more likely here.

Determining DER sizing by peak demand

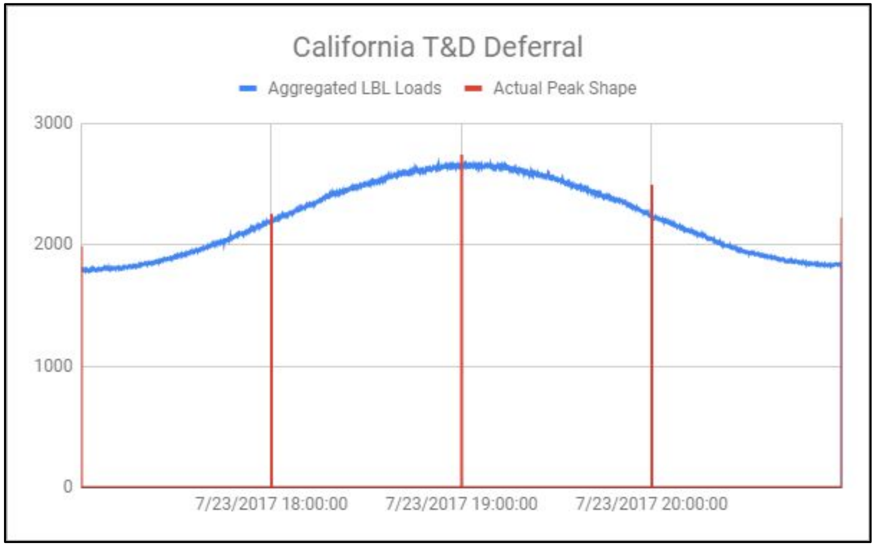
- Because a smaller circuit is being used, the DERs were scaled down to match the peak load.
  - Percent of Anza peak served by utility PV = 21.8% (3.4 MW total PV / 15.6 MVA total load)
    - Target utility-scale PV Capacity is **≥ 0.58 MW PV**
  - Percent of Anza peak served by rooftop PV = 9.0% (1.4 MW total PV / 15.6 MVA total load)
    - Target distributed PV Capacity is **≥ 0.24 MW PV**
  - Percent of Anza peak served by BESS = 12.8% (2 MW total BESS / 15.6 MVA total load)
    - Target BESS Capacity is **≥ 0.34 MW BESS** @ 4 hours
  - Anza Transmission Line Capacity is 15 MVA, which is 96% of their peak.
    - Target transmission line capacity is **2.6 MVA**

** Unless otherwise stated, information was sourced from Anza Electric Cooperative's website*

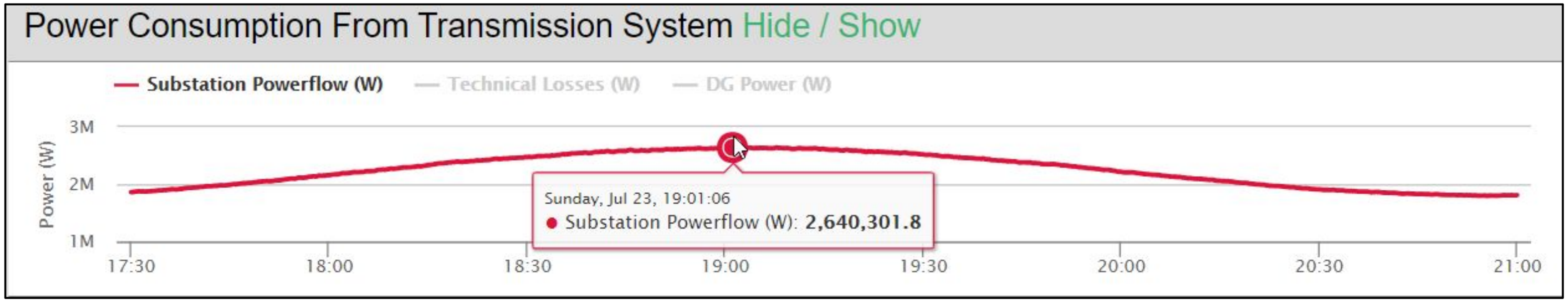
1) Deferral for a Small California Town

Load Profile Creation

- Loadshapes currently in use are those provided in LBL's initial ieee37 test package (commit 42b66d1). These were scaled to approximate the pattern of a real-world peak of this type (see right).
- The target aggregate loadshape peak is 2.6 MVA, corresponding to 4% overage based on ieee 37 substation rating of 2.5 MVA.



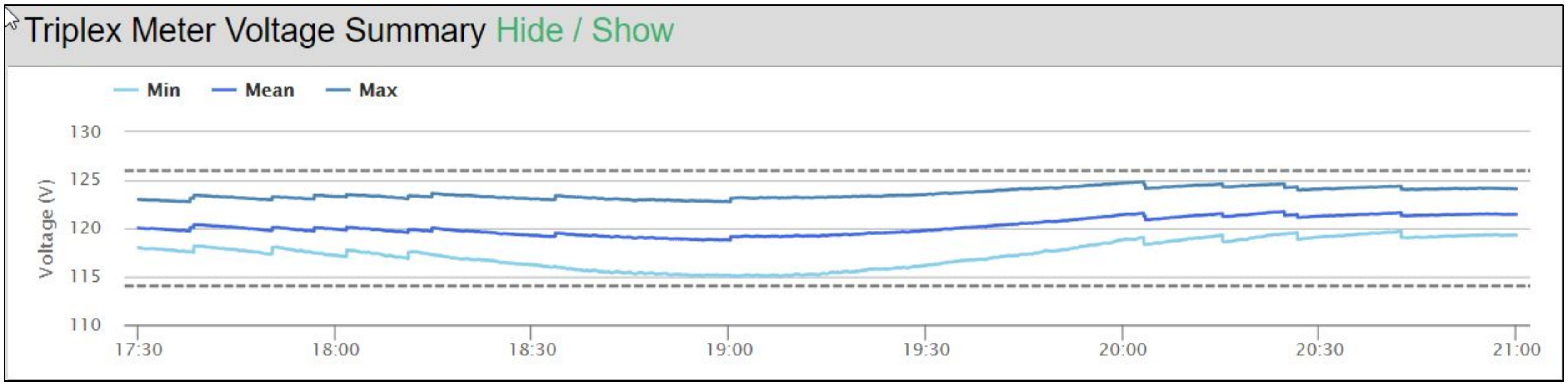
The load profiles provided by LBL were scaled to mimic the shape and magnitude of a demand peak taken from utility data.



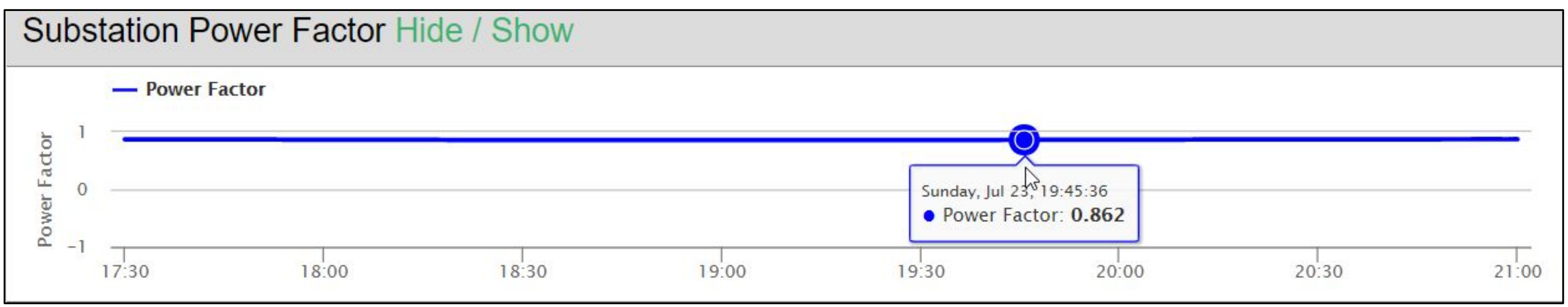
The circuit demand is ~2.6 MW, which exceeds the circuit's rated maximum of 2.5 MW by 4%.

1) Deferral for a Small California Town

- Shown below are the OMF results for the ieee37 with these loadshapes applied, but no PV and no batteries defined on the circuit. Input files located here.



Summary of triplex meter voltages across the ieee37 with no pv and no battery on the circuit. The ANSI band is respected for all bus voltages.

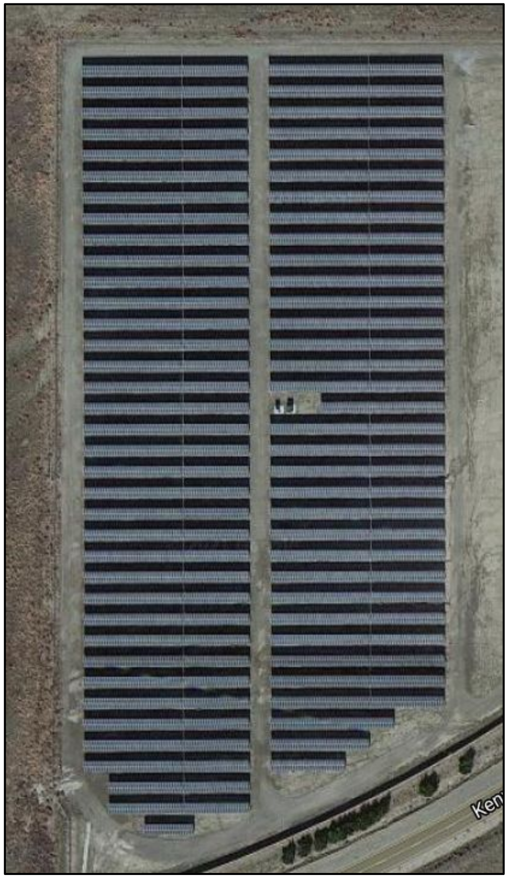


The system's power factor is poor at ~0.86, but matches the expected results as stated by ieee documentation.

Use Case 1A: Deferral with Centralized Utility-Owned Assets

In this scenario, PV and BESS are modeled as one utility-scale installation.

- Used the Phase 1 SunAnza installation at 1.4 MW.
  - (PV Capacity target is ≥ 0.58 MW)
- Used SunAnza Phase 2 battery at 2 MW / 4 MWh
  - (BESS Capacity target is ≥ 0.34 MW/0.68 MWh)
- This battery and PV system are co-located.
- Scenario takes place on July 23, 2017 from 17:00 to 21:00 local time. The peak occurs between 18:00 and 20:00 This type of peak occurs only a few times each year.
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL's initial ieee37 test package (commit 42b66d1).
- Utility-scale batteries use centralized control (i.e. battery_peak_shaving_controller_cent)
- The battery starts at 80% charge.
- The apparent_power_target' parameter of the battery controller is set to 2.5 MVA.

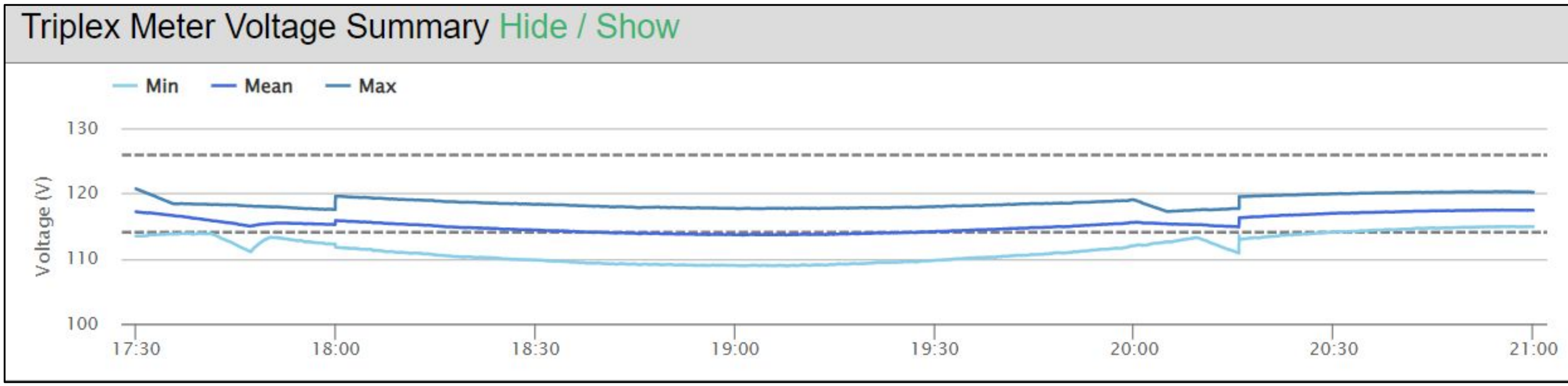


SunAnza Photovoltaic Plant after completing Phase 2 of the PV installation. (8400 panels @ 404W = 3.4 MW)

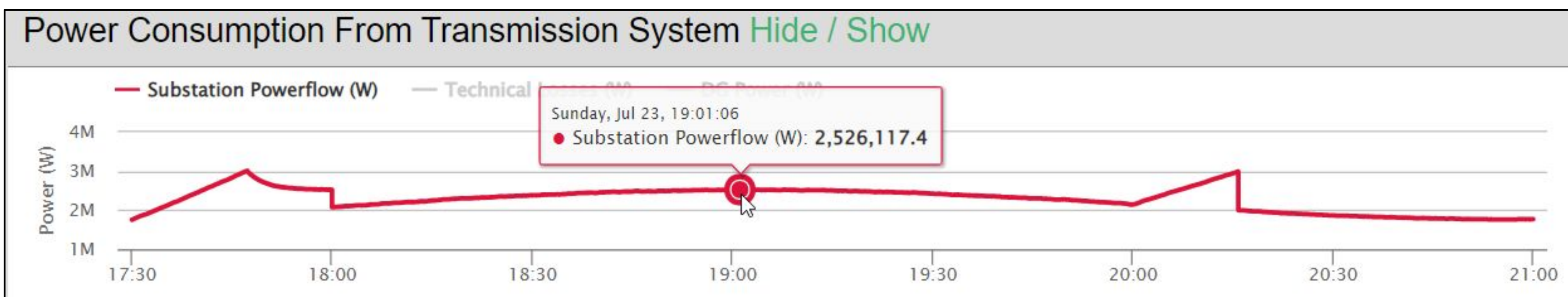
Use Case 1A: Deferral with Centralized Utility-Owned Assets

Resulting behavior of this scenario is shown below.

- Power factor is in the range 0.891 - 0.936. Input Files located here.



Triplex meter voltage distribution for the California use case with utility-scale PV and BESS. The addition of these DERs pushes the voltages out of the ANSI band.



Substation power for the California use case with utility-scale PV and BESS. The peak is designated between 18:35 and 19:32 and comprises ~0.1 MWh, which should be successfully mitigated by the 2 MW / 4 MWh BESS.

Use Case 1B: Deferral with Distributed Utility-Owned Assets

In this scenario, PV is modeled as two co-located PV-BESS utility-scale installations of equal sizing. Combined, the two installations have aggregate specs equal to that of use case 1A.

- One PV-BESS site is located at the substation
  - Location: bus 701
  - Co-load: 701a
  - PV: 0.7 MW
  - BESS: 1MW / 2 MWh

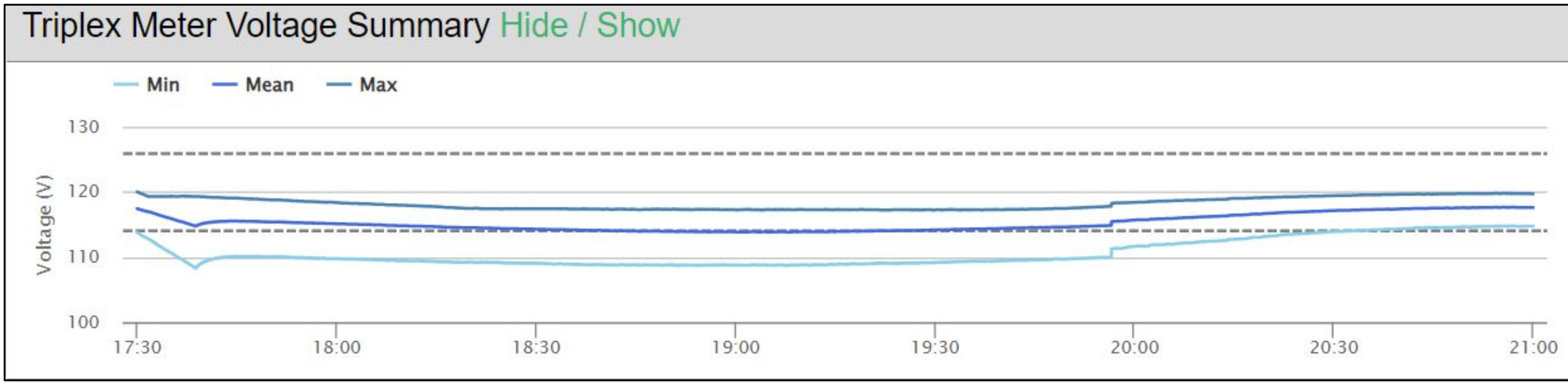
- The other PV-BESS site is located near the physical middle of the feeder
  - Location: bus 730
  - Co-load: s730c
  - PV: 0.7 MW
  - BESS: 1MW / 2 MWh

- Each of these use a local controller (battery_controller_dist)
- All other parameters are the same as use case 1A.

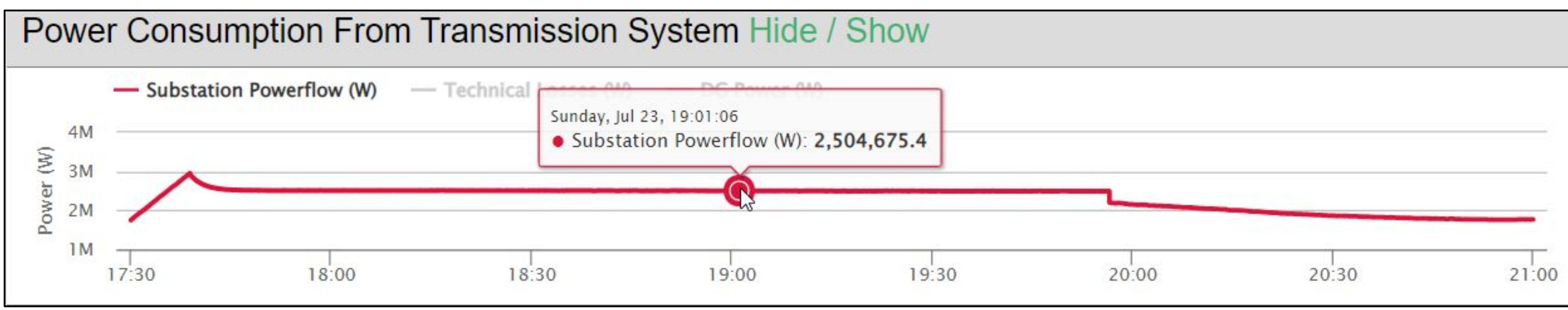
Use Case 1B: Deferral with Distributed Utility-Owned Assets

Resulting behavior of this scenario is shown below.

- Power factor is in the range 0.889 - 0.937. [Input files located here](#).



Triplex meter voltage distribution for the California use case with two installations of utility-scale PV and BESS. The voltages still fall outside of the ANSI band.



Substation power for the California use case with utility-scale PV and BESS. The peak is designated between 18:35 and 19:32 and can be successfully mitigated by the 2 MW / 4 MWh BESS. Note a slightly steeper slope around 19:45.

Use Case 1C: Deferral with Distributed Residential Assets

In this scenario, PV is modeled as multiple rooftop systems with aggregate capacity of 0.24 MW.
*Utilities would rely on directly controllable assets for this critical grid service.

- 118 2.1 kW rooftop systems were placed randomly across 1065 meters.
  - Anza's system shows an average of 2.5 kVA peak demand per meter.
  - The ieee37's peak demand implies there are 1065 meters. At 11% penetration, there would be 118 meters with rooftop solar.
    - Sanity check: 118 meters * 2.1 kW average system size = 0.25 MW (Great!)
- Of these 118 rooftop solar installations, 30% are assumed to have battery storage (n=39).
  - One Tesla Powerwall 2 (5.8kW / 13.5 kWh) per installation with 80% charge available.
  - The battery discharge power is set to 75% of maximum rated power.
- Siting is chosen randomly and according to the number of meters implied by the load's rated apparent power. (see figure)
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL's initial ieee37 test package (commit 42b66d1).
- BESS control is centralized.
- The apparent_power_target' parameter of the battery controller is set to 2.5 MVA.
- BESS dis/charge is staggered to simulate many batteries independently entering peak shave.

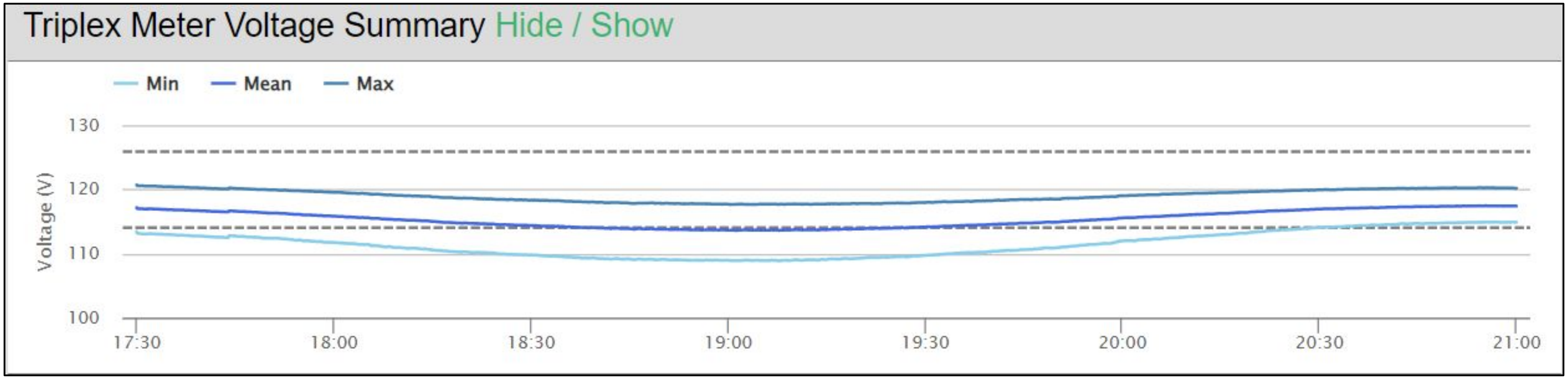
load ID	kW	kvar	apparent power (kVA)	# households @ 2.5kW each
s701a	140	70	156.5247584	62
s701b	140	70	156.5247584	62
s701c	350	175	391.3118961	156
s712c	85	40	93.94147114	37

Determining the number of households represented by each ieee37 load, as informed by real system parameters at Anza Electric in California.

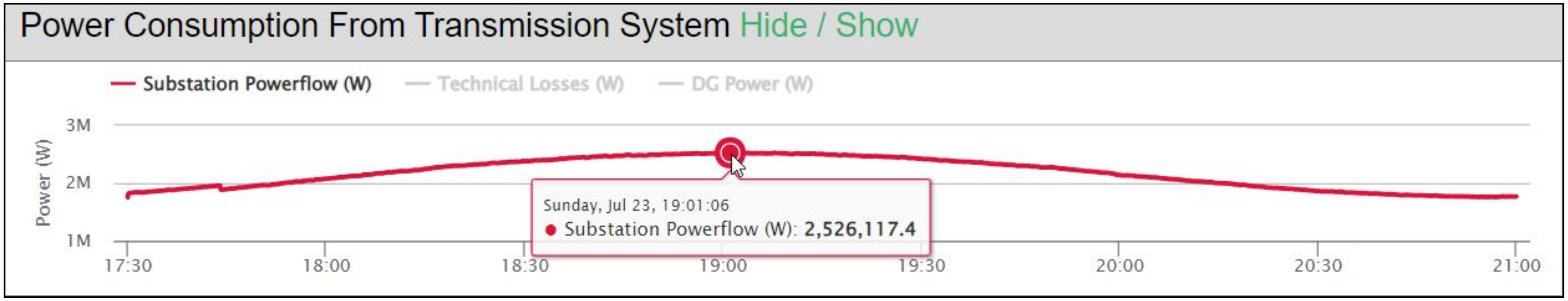
Use Case 1C: Deferral with Distributed Residential Assets

Resulting behavior of this circuit is shown below.

- Power factor is in the range 0.891 - 0.915. Input files located here.



Triplex meter voltage distribution for the California use case with distributed residential PV and BESS. The addition of these DERs pushes the voltages out of the ANSI band.



Substation power for the California use case with distributed residential PV and BESS. The peak is designated between 18:35 and 19:32 and can be successfully mitigated by the 2 MW / 4 MWh BESS. Note a slightly steeper slope around 19:45.

2) Peak Shaving in the Colorado Foothills

General scenario information

- Use Case: Peak Shaving
- Lat, long: 39.896592, -104.860411
- State(s): Colorado
- Counties: Boulder, Adams, Clear Creek, Weld, Broomfield
- Peak demand: 476 MW (summer); 341 MW (winter)
- PV Penetration: 6.1%
- Circuit file: ieee37_LBL.dss (37 nodes, 2662 kVA of loads)

Two typical homes in Brighton, CO.

Existing PV installation information

- Rattlesnake Solar Field - 16 MW
- Platte Solar Field - 16 MW
- Mavericks Solar Field - 7.5 MW
- Fort Lupton Solar Field - 13 MW
- Sol Partners Community Solar Garden - 96 3.5' x 5' panels at 400W ≈ 0.04 MW
- Hangar 160 Community Solar Garden - 2.8 MW
- 6100+ rooftop PV systems
  - 28 MW distributed renewables = 84 MW total renewables minus 56 MW utility-scale, assuming the rest are residential PV systems.
  - This is out of 100,000 meters, yielding PV penetration of 6.1%.
  - Average size of residential PV system for this area is 4.6 kW (28 MW/6100 systems)

*** Unless otherwise stated, information was sourced from United Power Electric Cooperative's website*

2) Peak Shaving in the Colorado Foothills

BESS installation information

- Carbon Valley Battery System - 4 MW / 16 MWh Tesla Powerpack
  - Location: 40.140354, -104.977806
- United Power Office Battery System - 0.5 MW / 2 MWh Tesla
  - Location: 39.980317, -104.741766 (colocated with Sol Partners PV Garden)

Other information

- There's a 3.2 MW landfill methane-to-energy project in the town of Erie.
- There are at least 2 EV fast-chargers.
- This scenario takes place on August 4, 2015 from 17:00 to 21:00 local time.
- Sunset occurs between 20:00 and 22:00.

Determining demand and generation asset proportions

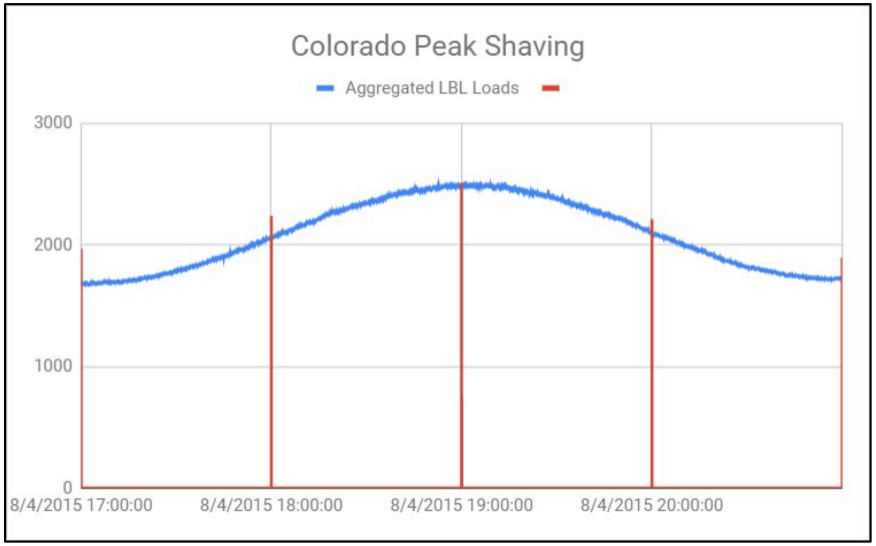
- Because a smaller circuit is being used, the DERs were scaled down to match the peak load.
  - Percent of UP peak served by utility PV = 11.8% (56 MW total PV / 476 MVA total load)
    - Target utility-scale PV Capacity is **≥ 0.3 MW PV**
  - Percent of UP peak served by rooftop PV = 5.9% (28 MW total PV / 476 MVA total load)
    - Target distributed PV Capacity is **≥ 0.16 MW PV**
  - Percent of UP peak served by BESS = 0.95% (4.5 MW total BESS / 476 MVA total load)
    - Target BESS Capacity is **0.025 MW BESS** @ 4 hours

*** Unless otherwise stated, information was sourced from United Power Electric Cooperative's website*

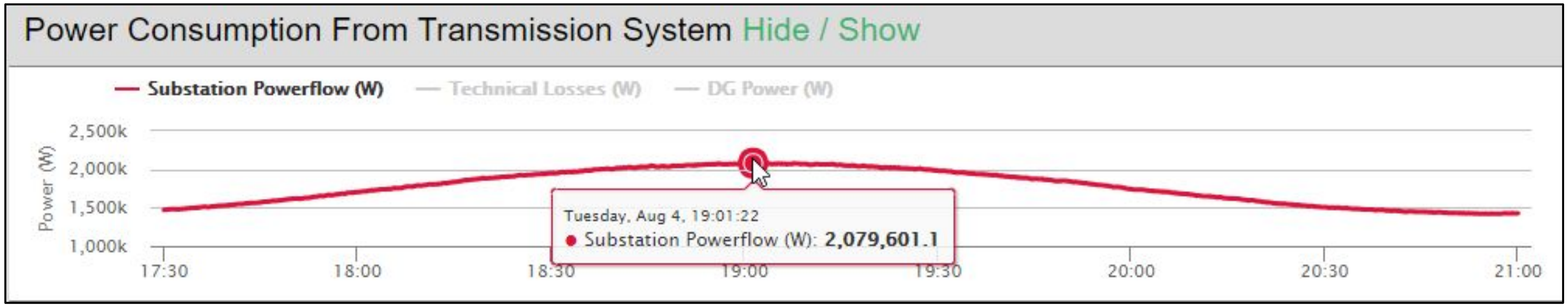
2) Peak Shaving in the Colorado Foothills

Load Profile Creation

- Loadshapes currently in use are those provided in LBL's initial ieee37 test package (commit 42b66d1). These were scaled to approximate the pattern of a real-world peak of this type (see right).
- The target aggregate loadshape peak is 2.1 MVA, corresponding to 84% of rated substation power at 2.5 MVA.



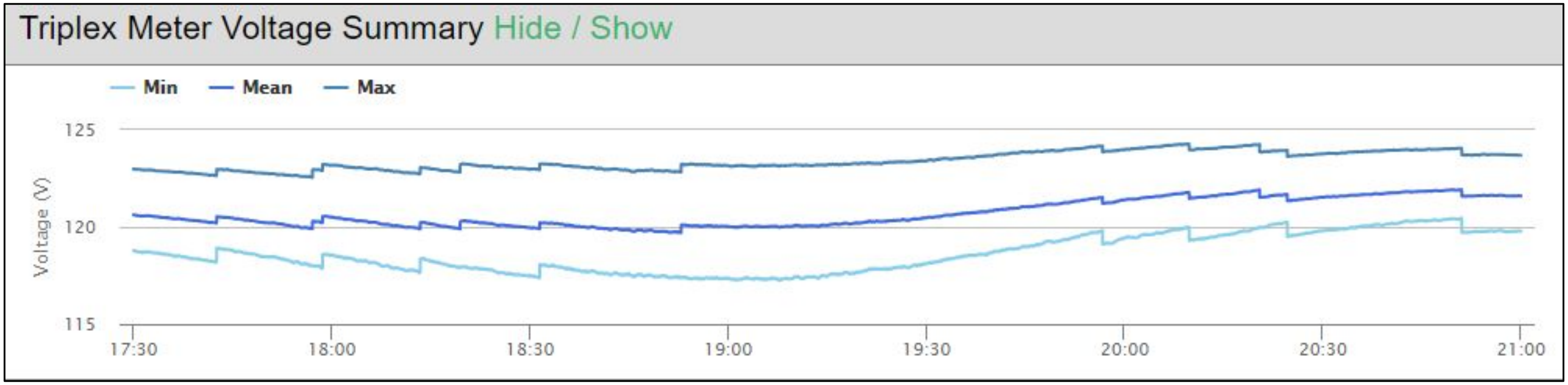
The load profiles provided by LBL were scaled to mimic the shape and magnitude of a demand peak taken from utility data.



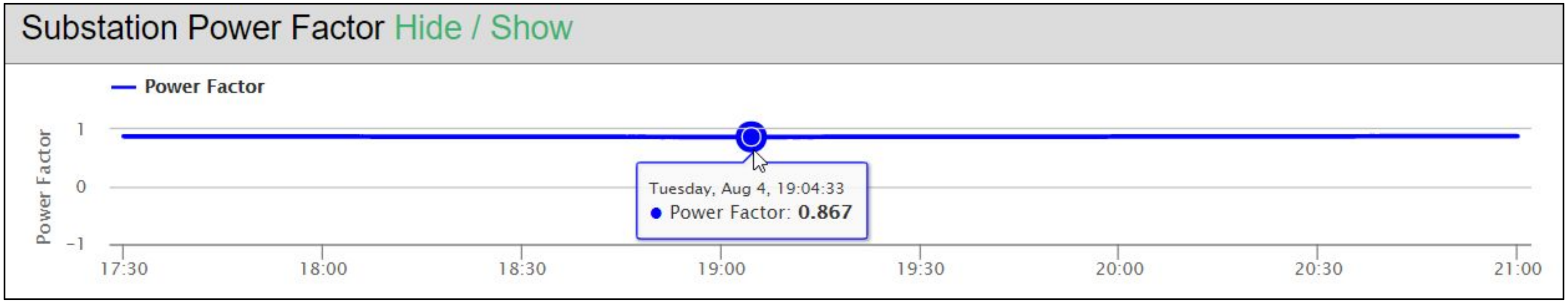
The circuit demand is ~2.1 MW, which is 84% of the circuit's rated maximum of 2.5 MW.

2) Peak Shaving in the Colorado Foothills

- Shown below are the OMF results for the ieee37 with these loadshapes applied, but no PV and no batteries defined on the circuit. Input files located here.



Summary of triplex meter voltages across the ieee37 with no pv and no battery on the circuit.

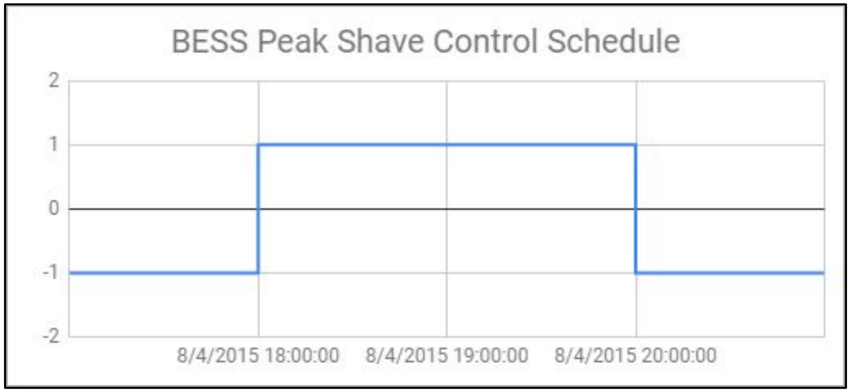


The system's power factor is poor at a range of 0.867 - 0.879, but matches the expected results as stated by ieee documentation.

Use Case 2A: Peak Shaving with Centralized Utility-Owned Assets

In this scenario, PV and BESS are modeled as a utility-scale installation.

- Uses Hangar 160 Solar Garden at 2.8 MW
  - (PV Capacity target is ≥ 0.3 MW)
- Used UP office battery at 0.5 MW / 2 MWh
  - (BESS Capacity target is ≥ 0.025 MW/0.1 MWh)
- This battery and PV system are modeled as co-located systems.
- Scenario takes place on August 4, 2015 from 17:00 to 21:00 local time. The peak occurs between 18:00 and 20:00. These peaks are shaved on a monthly basis.
- A BESS control schedule (shown below) indicates on- and off-peak times and informs BESS behavior.
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL's initial ieee37 test package (commit 42b66d1).
- BESS control is centralized.



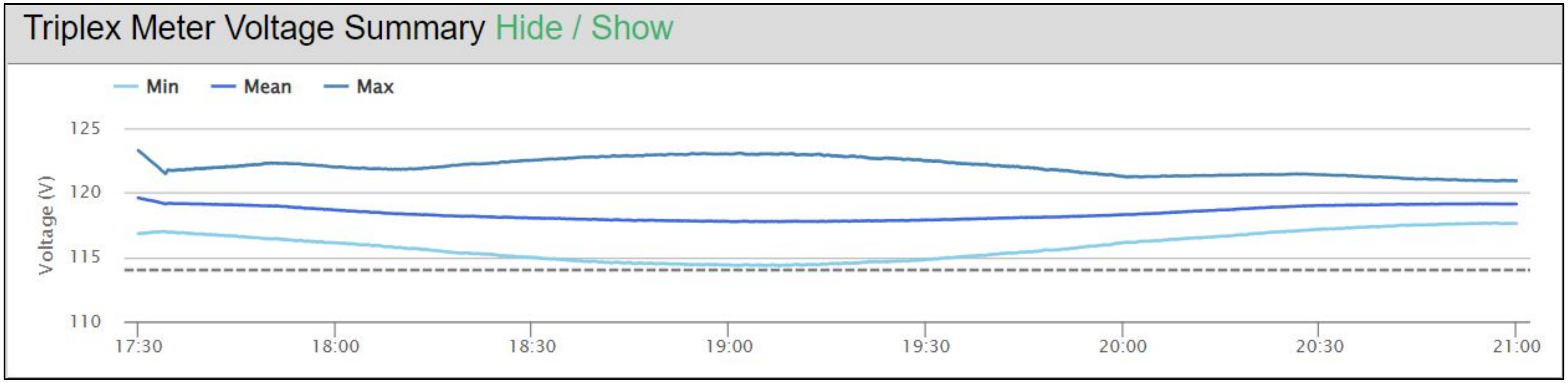
On- and Off-Peak times are defined in a .csv that is passed to PyCigar. The following enumeration applies: -1=Off-Peak; 0=Undefined; 1=On-Peak. For this use case, the peak is defined between 6:00 PM and 8:00 PM.

Sol Partners community Solar Garden co-located with Tesla PowerPack

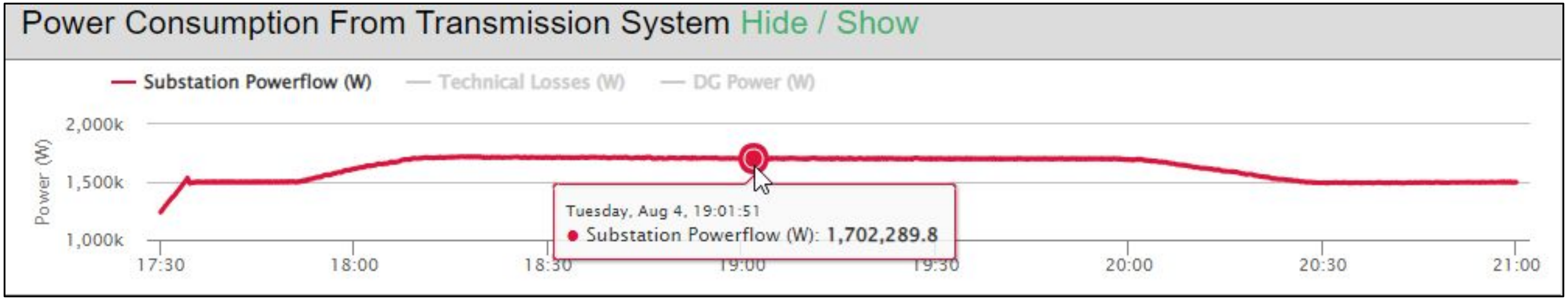
Use Case 2A: Peak Shaving with Centralized Utility-Owned Assets

Resulting behavior of this circuit is shown below.

- Power factor is in the range 0.939 - 0.947. Input files located here.



Triplex meter voltage distribution for the Colorado use case with utility-scale PV and co-located battery. Results are within the ANSI band, indicated by dotted line.



Substation power for the Colorado use case with utility-scale PV and co-located battery. The peak is designated between 18:00 and 20:00 and the battery is 0.5 MW / 2 MWh. The battery can be seen charging after 20:00 because the designated peak has passed.

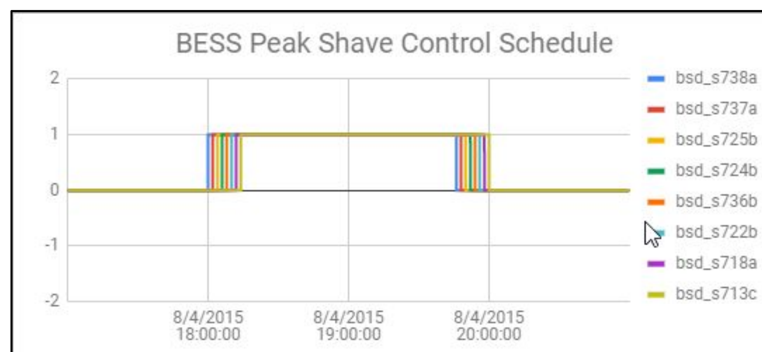
Use Case 2B: Peak Shaving with Distributed Residential Assets

In this scenario, PV is modeled as multiple rooftop systems with aggregate capacity of 0.16 MW.

- 33 4.6 kW rooftop systems were placed randomly across 555 meters.
  - UP's system shows an average of 4.8 kVA peak demand per meter.
  - The ieee37's peak demand implies there are 555 meters.
  - At 6.1% penetration there would be 33 meters with rooftop solar.
    - Sanity check: 33 meters * 4.6 kW average system size ≈ 0.16 MW (Great!)
- Of these 33 rooftop solar installations, 30% are assumed to have battery storage (n=11)
  - One Tesla Powerwall 2 (5.8kW / 13.5 kWh) per installation at 80% charge.
  - The battery discharge ramp rate is set to 75% of full power.
- Siting is chosen randomly and according to the number of meters implied by the load's rated apparent power. (see figure)
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL's initial ieee37 test package (commit 42b66d1).
- BESS on-peak definitions are staggered by 1 minute to avoid transients in the results.
- BESS control is local.

load ID	kW	kvar	apparent power (kVA)	# households @ 4.8kW each
s701a	140	70	156.5247584	32
s701b	140	70	156.5247584	32
s701c	350	175	391.3118961	81

Determining the number of households represented by each ieee37 load, as informed by real system parameters at United Power in Colorado.

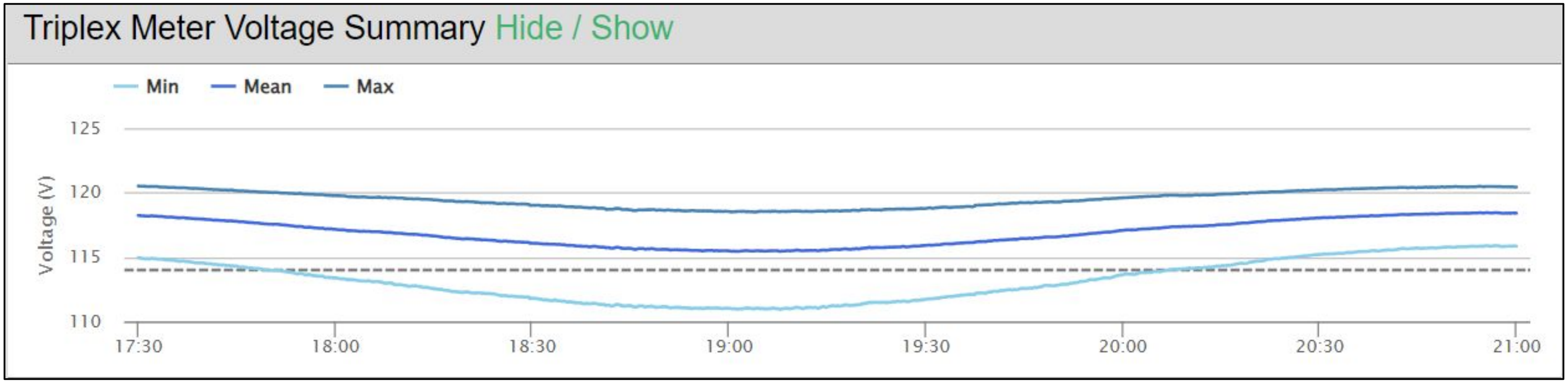


Control schedules for select batteries. Each is offset by 1 minute. The following enumeration applies: -1=Off-Peak; 0=Undefined; 1=On-Peak.

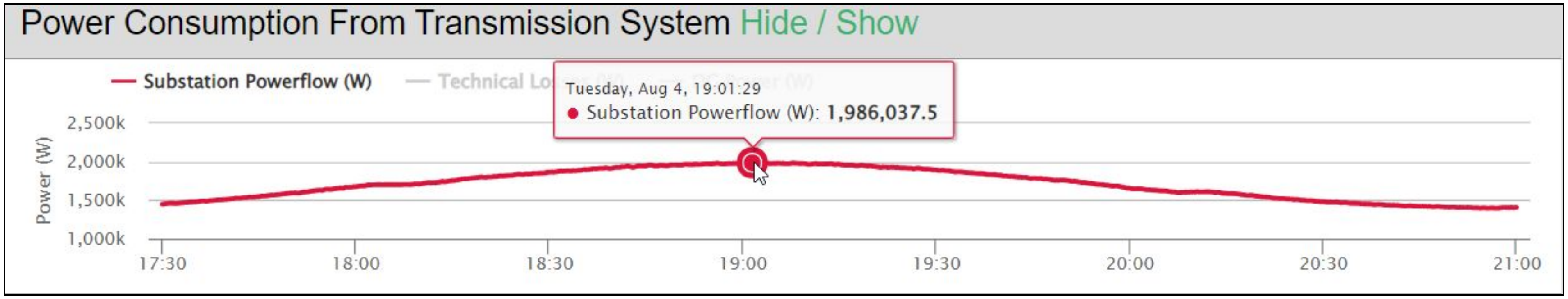
Use Case 2B: Peak Shaving with Distributed Residential Assets

Resulting behavior of this circuit is shown below.

- Power factor is in the range 0.868 - 0.884. Input files located here.



Triplex meter voltage distribution for the Colorado use case with distributed BESS co-located with residential PV. No utility-scale installations are included. Once the DERs are added, the voltages fall outside the ANSI band.



Substation power for the Colorado use case with distributed BESS co-located with residential PV. The peak is designated between 18:00 and 20:00. The 11 5.8kW / 13.5 kWh battery systems are charging and discharging at unexpected times.

Use Case 2C: Peak Shaving with Utility-Owned and Residential Assets

In this scenario, the distributed and utility-scale scenarios are combined into a hybrid model.

- Utility-scale PV and BESS is modeled as a single co-located installation as in use case 2A.
  - PV capacity: 2.8 MW
  - BESS capacity: 0.5 MW
  - BESS max energy: 2.0 MWh
  - BESS control: Central (i.e. battery_controller_cent)
  - On-peak scheduling for the BESS is between 18:00 and 20:00.

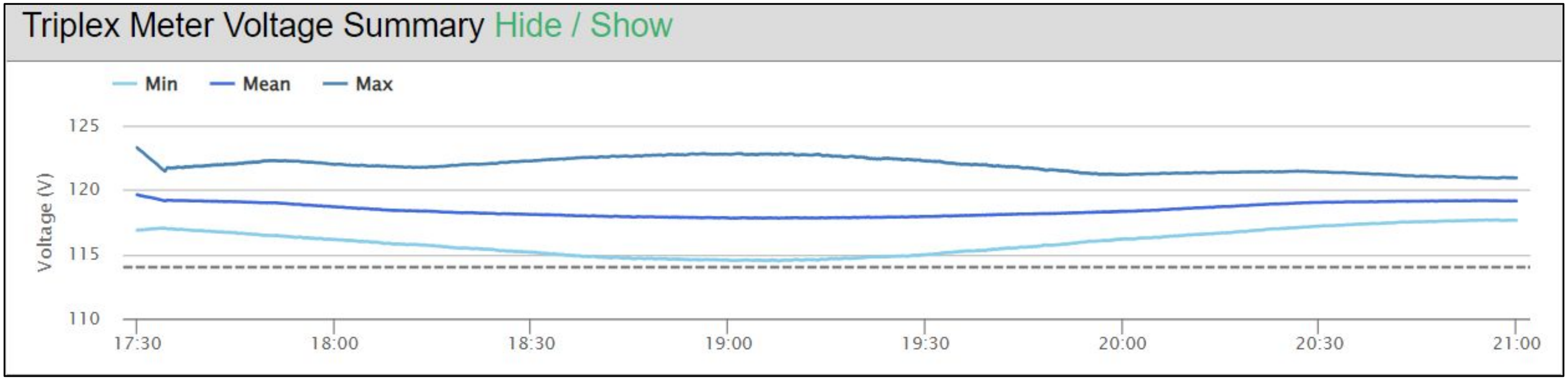
- Distributed PV and BESS are modeled as multiple co-located rooftop systems with sizing, siting, and scheduling as described in use case 2B.
  - PV capacity: 0.16 MW (in aggregate)
  - BESS capacity : 63.8 kW (in aggregate)
  - BESS max energy: 148.5 kWh (in aggregate)
  - BESS control: Local (i.e. battery_controller_dist)
  - On-peak scheduling for each BESS are defined 1 minute apart

- Distributed and utility-scale installations may be located at the same bus, but do not share the same phase.

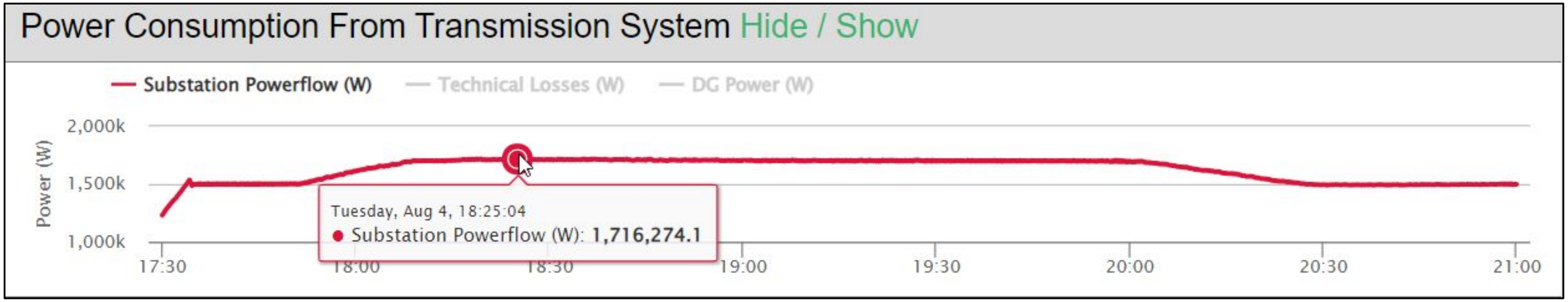
Use Case 2C: Peak Shaving with Utility-Owned and Residential Assets

Resulting behavior of this circuit is shown below.

- Power factor is in the range 0.939 - 0.948. Input files located here.



Triplex meter voltage distribution for the Colorado use case with utility-scale PV but no battery on the circuit. As the voltage falls outside the ANSI band (indicated by dotted line), the regulator undergoes tap changes that are unable to maintain the voltage.



Substation power for the Colorado use case with distributed BESS co-located with residential PV. The peak is designated between 18:00 and 20:00. The 11 5.8kW / 13.5 kWh battery systems are charging and discharging at unexpected times.

3) Backup for an East Coast Island

General scenario information

- Use Case: Backup power
- Lat, long: 35.111835, -75.974972
- State(s): North Carolina
- Countie(s): Hyde
- Peak demand: 5 MVA (summer); 1 MVA (winter)
- PV Penetration: 1% (up to 15% for demo purposes)
- Circuit file: (temp) ieee37_LBL.dss (2500 kVA)

Properties on Okracoke Island tend to be compact, multi-story, and lacking residential solar.

Existing PV installation information

- 15 kW PV
- Location: 35.109429, -75.980432
  - on top of the diesel generator housing at substation
- Very little residential solar (any?)

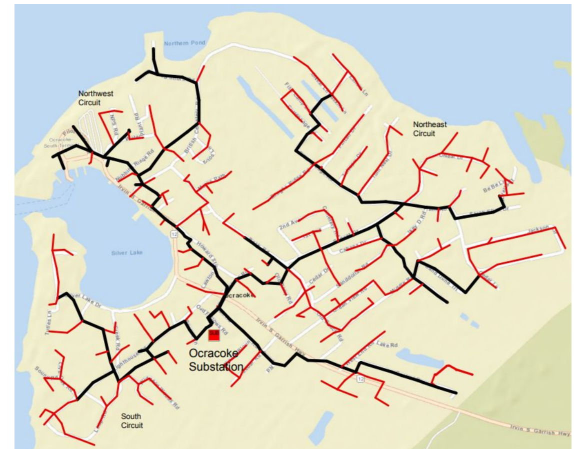
BESS installation information

- 0.5 MW / 1 MWh
  - Location: 35.109429, -75.980432 (at substation)
  - Serves the load through the time it takes to start diesel generator (about 10 minutes?)

3) Backup for an East Coast Island

Other information

- Diesel generation of 3MW.
- Demand response program (~750kW reduction? need sources)
  - 50 water heaters
  - 175 thermostats
- Sunset on August 26, 2011 occurs from 19:39 to 21:08.
- The Island experiences heavy tourism in Summer months.
- Energy rates are $0.08 - $0.12/kWh



The Okracoke Substation circuit map.

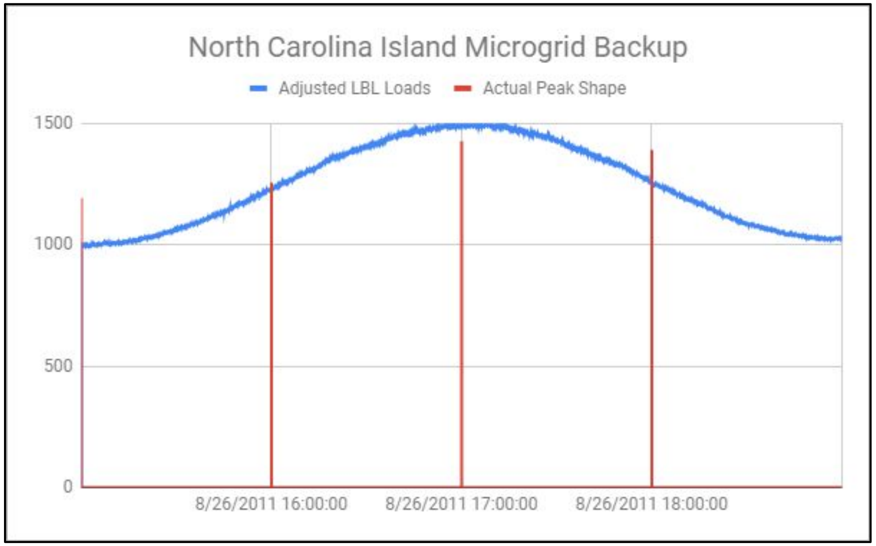
Determining DER sizing by peak demand

- Electricity is served to 1385 meters on Okracoke, representing a max demand of 5MVA in Summer. For this simulation, half the meters (692) will be represented to achieve a designed max peak of 2500 kVA in Summer and 500kVA in Winter.
- Average demand per meter is best determined using Winter demand since tourism is not as prevalent:
  - According to US Census, there are 560 residences, half of which (280) are being represented in this sim.
  - It is possible that 60% of all residences are occupied in Winter (168 homes).
  - Winter peak (500MW) / 168 homes = 3kW average demand.

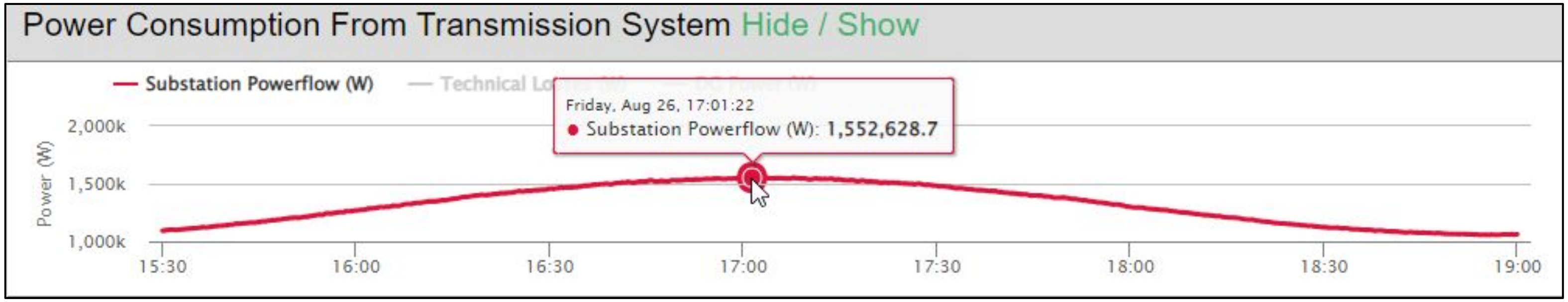
3) Backup for an East Coast Island

Load Profile Creation

- This simulation occurs during peak tourist (aka max demand) season.
- It also occurs during peak storm season. The scenario modeled involves an outage during a severe tropical storm.
- The target aggregate load value is set to 60% of designed peak (~1.5 MW) because:
  - The island's occupants are aware of the incoming storm and have either evacuated or reduced consumption to necessary loads.
  - The demand response program is active in anticipation of constrained resources.
- Loadshapes currently in use are those from LBL's initial ieee37 test package (commit 42b66d1)



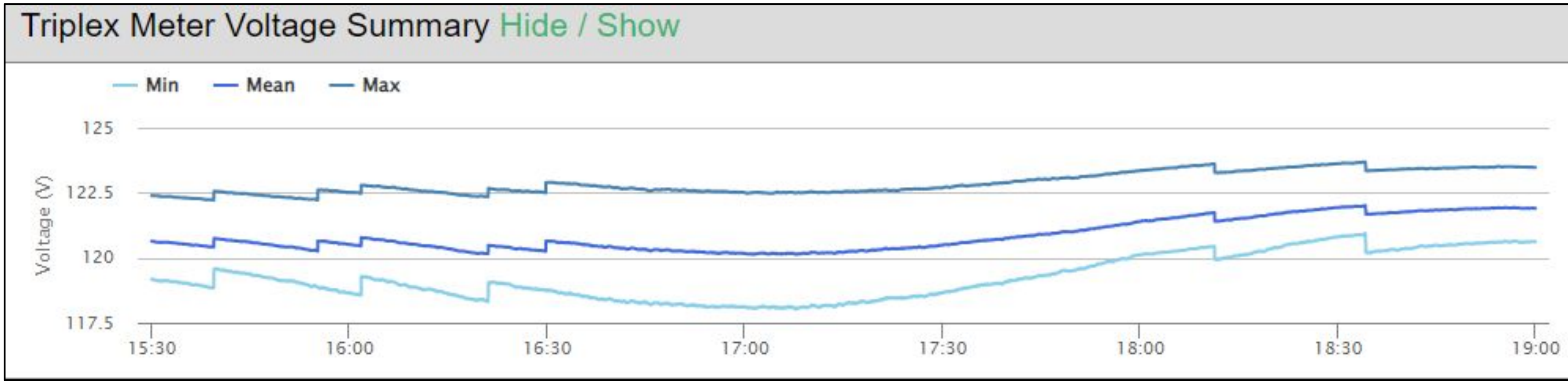
The load profiles provided by LBL were scaled to mimic the shape and magnitude of demand curves taken from utility data.



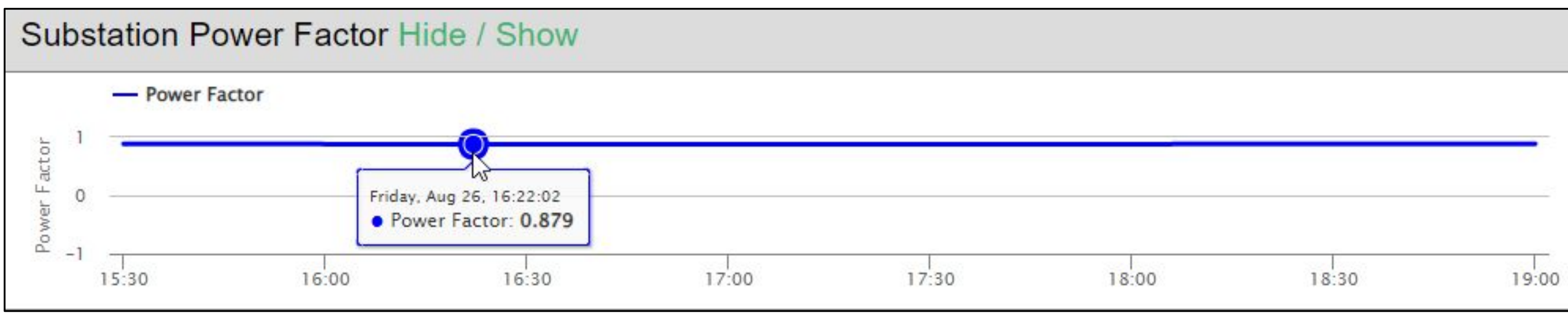
The circuit demand is ~1.5MVA, which is 60% of the circuit's rated maximum of 2.5 MVA.

3) Backup for an East Coast Island

Shown below are the OMF results for the ieee37 with these loadshapes applied, but no PV and no batteries defined on the circuit. [Input files located here].



Summary of triplex meter voltages across the ieee37 with no pv and no battery on the circuit. The ANSI band is respected for all bus voltages.

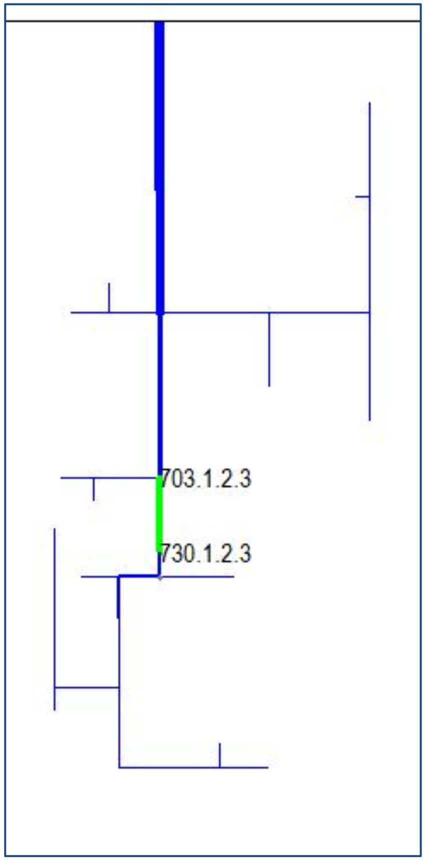


The system's power factor is around 0.88, but matches the expected results as stated by ieee documentation.

Use Case 3A: Downline Backup with Utility-Owned and Residential Assets

In this scenario, a microgrid consisting of utility-scale PV, BESS and diesel generation works alongside residential PV and BESS to support a specific section of the full circuit.

- This scenario models an outage during the early stages of hurricane Irene, which made landfall on North Carolina's Outer Banks around 8am on August 27, 2011.
- The experiment takes place between 15:00 and 19:00 on August 26, 2011, when strong winds winds were beginning to fell trees. At 16:00, a vulnerable section of line is damaged and the downline system goes into backup/islanded mode. The battery is used to serve the load while the diesel generator starts up.
- Microgrid boundary definition:
  - Microgrid serves load downline of line.L6 (between buses 703 and 730)
  - Microgrid serves aggregate max rated load of 955kVA. This is 35% of the overall circuit.
  - Estimated that microgrid serves around 60 permanent homes, 40 vacation homes, and 140 other meters.
- PV:
  - Utility-owned: 15kW on same bus as diesel
  - Consumer-owned: Tideland EMC wants to install additional PV resources on Okracoke, but faces barriers due to land use and wind speed resistance. This scenario takes place in a future where Tideland has overcome these challenges, resulting in ~20% penetration. This equals about 20 installs. At 5kW each, the microgrid contains an additional 100kW of rooftop solar.
  - Solar production during the experiment is reduced by 40% to simulate cloud cover from the approaching storm.
- BESS:
  - Utility-owned: 0.5MW/1MWh @half = 0.25MW/0.5MWh. Added to bus 730
  - Consumer-owned: Assume 30% of the rooftop PV installs are coupled with Tesla Powerwalls at 5.8kW / 13.5 kWh each. This yields 7 installs, for a total of ~ 40.6kW/ 94.5kWh non-utility BESS.
  - The batteries are assumed to have charged to 100% SOC.
- TODO: Add diesel to bus 730 in amount of 0.6MW (3MW*0.35/2 = 0.6MW)
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL's initial ieee37 test package (commit 42b66d1).

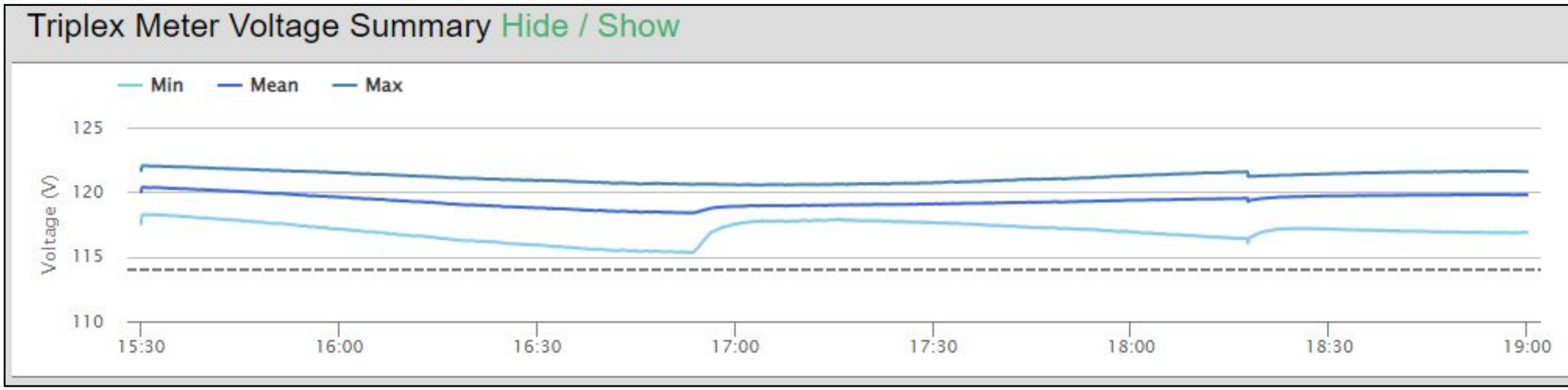


The microgrid serves load downline from bus 730, with its interconnection switch at line L6.

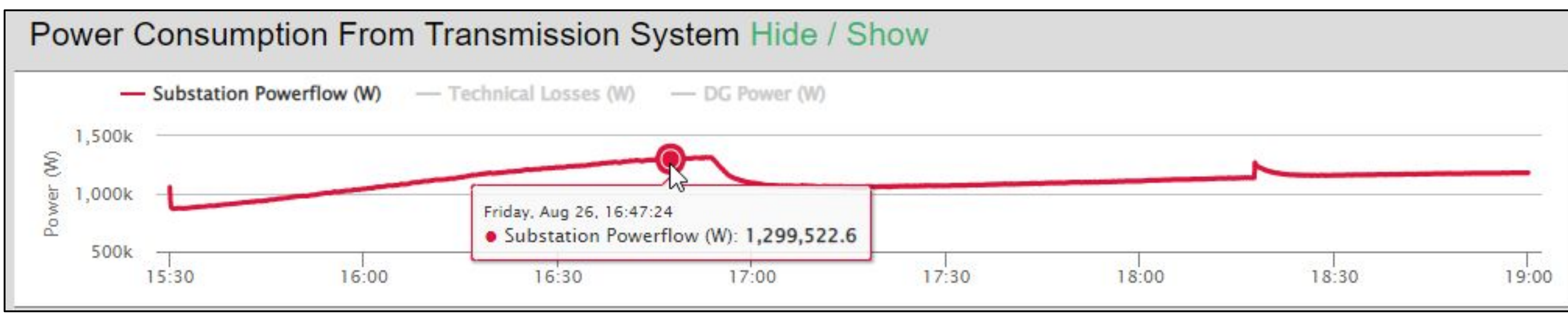
Use Case 3A: Downline Backup with Utility-Owned and Residential Assets

Resulting behavior of this scenario is shown below.

- Power factor is in the range 0.891 - 0.936. Input Files located here.



Triplex meter voltage distribution for the Okracoke Island use case with utility-scale PV and BESS as well as residential PV and BESS. The addition of these DERs pushes the voltages out of the ANSI band.



Substation power for the Okracoke Island use case with hybrid PV and BESS. Substation power is lost at 18:00 and the battery discharges until the diesel generators can take load at 18:10. The battery then supplements as needed to maintain service.

Use Case 3B: Substation Backup with Utility-Owned and Residential Assets

In this scenario, PV is modeled as multiple rooftop systems with aggregate capacity of 0.24 MW.
*Utilities would rely on directly controllable assets for this critical grid service.

- 118 2.1 kW rooftop systems were placed randomly across 1065 meters.
  - Anza’s system shows an average of 2.5 kVA peak demand per meter.
  - The ieee37’s peak demand implies there are 1065 meters. At 11% penetration, there would be 118 meters with rooftop solar.
    - Sanity check: 118 meters * 2.1 kW average system size = 0.25 MW (Great!)
- Of these 118 rooftop solar installations, 30% are assumed to have battery storage (n=39).
  - One Tesla Powerwall 2 (5.8kW / 13.5 kWh) per installation with 80% charge available.
  - The battery discharge power is set to 75% of maximum rated power.
- Siting is chosen randomly and according to the number of meters implied by the load’s rated apparent power. (see figure)
- Inverter breakpoints are as defined at each load by the breakpoints file provided with LBL’s initial ieee37 test package (commit 42b66d1).
- BESS control is centralized.
- The apparent_power_target’ parameter of the battery controller is set to 2.5 MVA.
- BESS dis/charge is staggered to simulate many batteries independently entering peak shave.

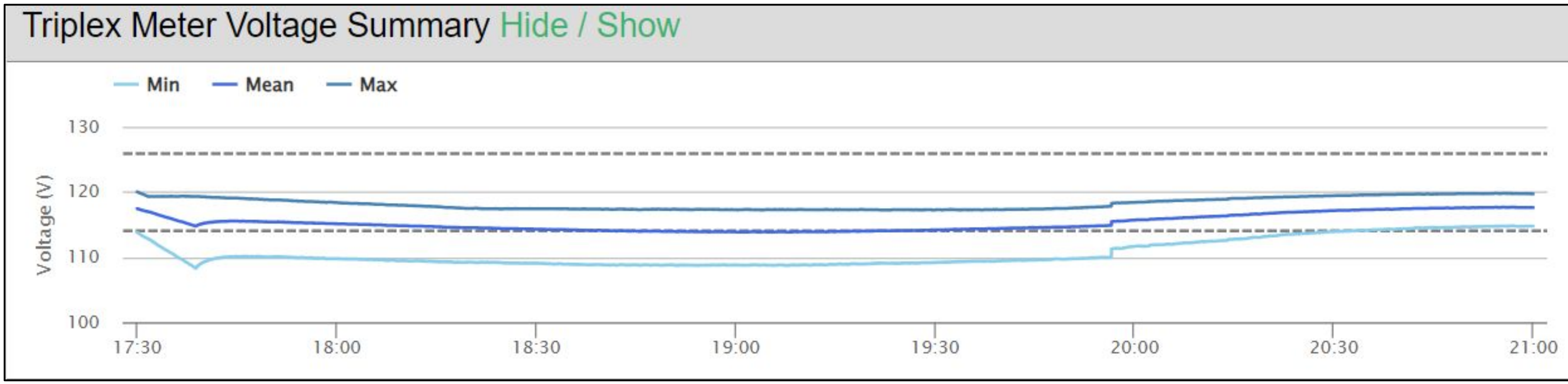
load ID	kW	kvar	apparent power (kVA)	# households @ 2.5kW each
s701a	140	70	156.5247584	62
s701b	140	70	156.5247584	62
s701c	350	175	391.3118961	156
s712c	85	40	93.94147114	37

Determining the number of households represented by each ieee37 load, as informed by real system parameters at Anza Electric in California.

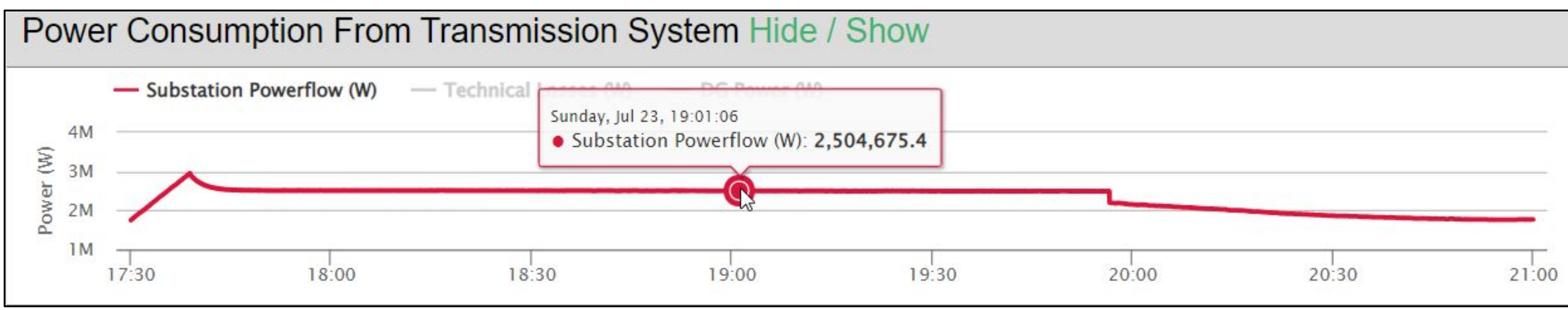
Use Case 3B: Substation Backup with Utility-Owned and Residential Assets

Resulting behavior of this scenario is shown below.

- Power factor is in the range 0.889 - 0.937. [Input files located here](#).



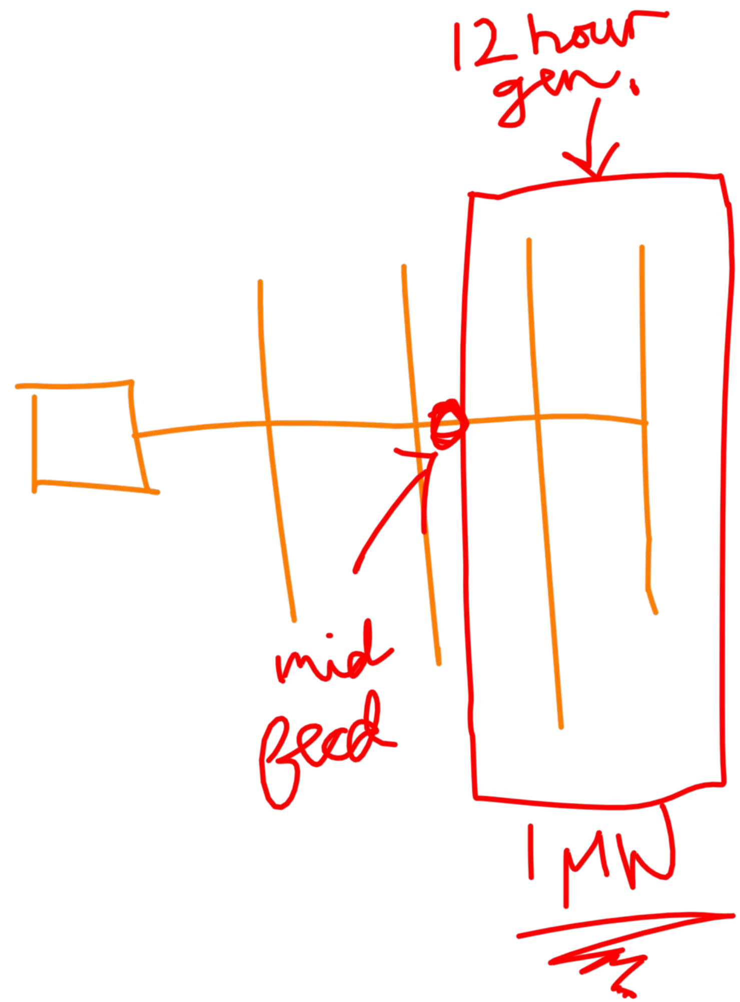
Triplex meter voltage distribution for the California use case with two installations of utility-scale PV and BESS. The voltages still fall outside of the ANSI band.



Substation power for the California use case with utility-scale PV and BESS. The peak is designated between 18:35 and 19:32 and can be successfully mitigated by the 2 MW / 4 MWh BESS. Note a slightly steeper slope around 19:45.

Case 3 Definition

- Put switch in middle of circuit, leaving half of circuit away from substation as roughly 1 MW of demand microgrid.
- Add generation to support microgrid for approx 12 hours:
  - 1 vsource to model diesel
  - 500 kW / 1000 MWh energy storage
  - 150 kW solar "utility scale"
  - 150 kW solar "consumer"
- We're going to need to open the switch for 4ish hours in the middle of the simulation
  - How does Sy-Toan specify events that happen during the sim time like switching?
  - Important discussion for LBNL: how do we simulate the diesel better than using a vsource!?!?! note that isource injection papers are very, very complicated



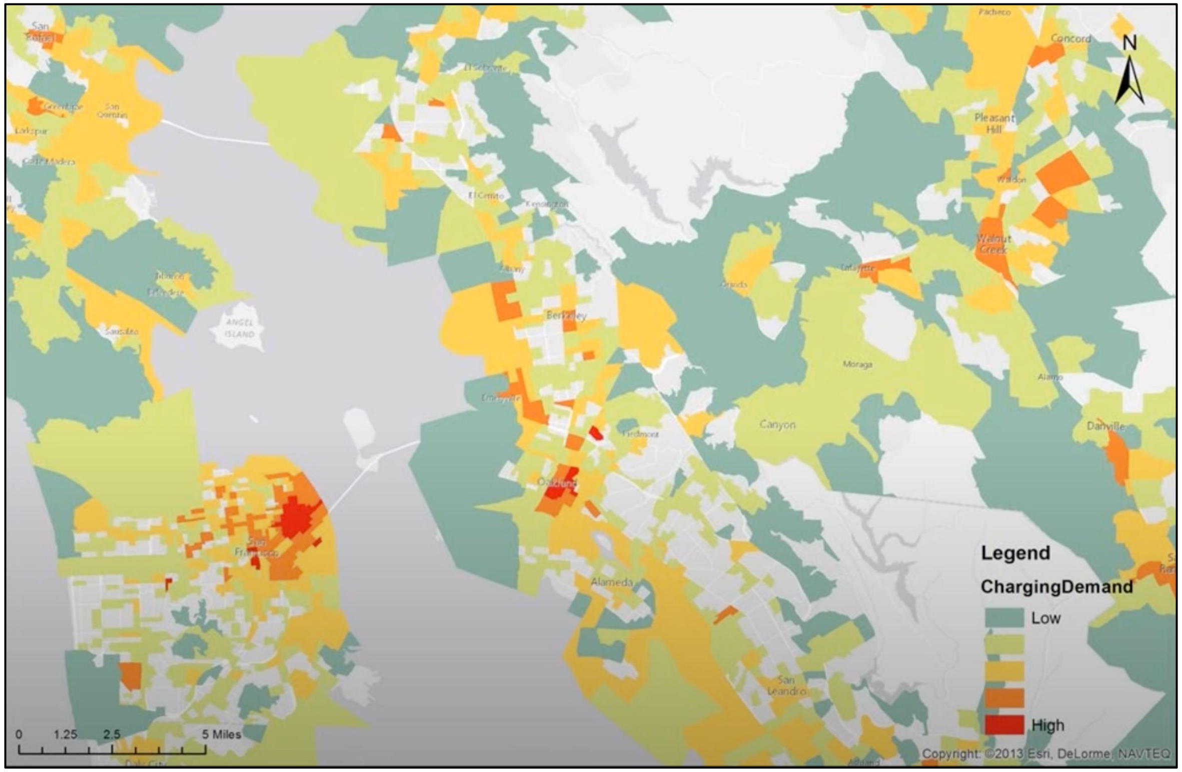
Next Steps

- Solidify battery control approaches and deploy.
- Review use cases in light of new control and revise as needed.
  - Add additional load complexity to introduce non-simultaneous load peaks, which will especially affect distributed peak shaving (case 2b and 2c).
  - Convert solar-plus-storage to EV batteries.
- Generate test files for microgrid use case.
- EV testing? See next slide.

Adding EV Loads (Future Work)

UC Davis and NRECA collaborated on an EV adoption forecasting tool ([GIS EV Planning Toolbox for MPOs]())

- Gives estimates of adoption based on a contagion model.
- Forecast only; actuals typically harder to come by via DMV records or inspecting AMI data.



Example output from the UC Davis EV Planning Toolbox for MPOs showing high charging demand as warm colors and low demand as cool colors.