U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

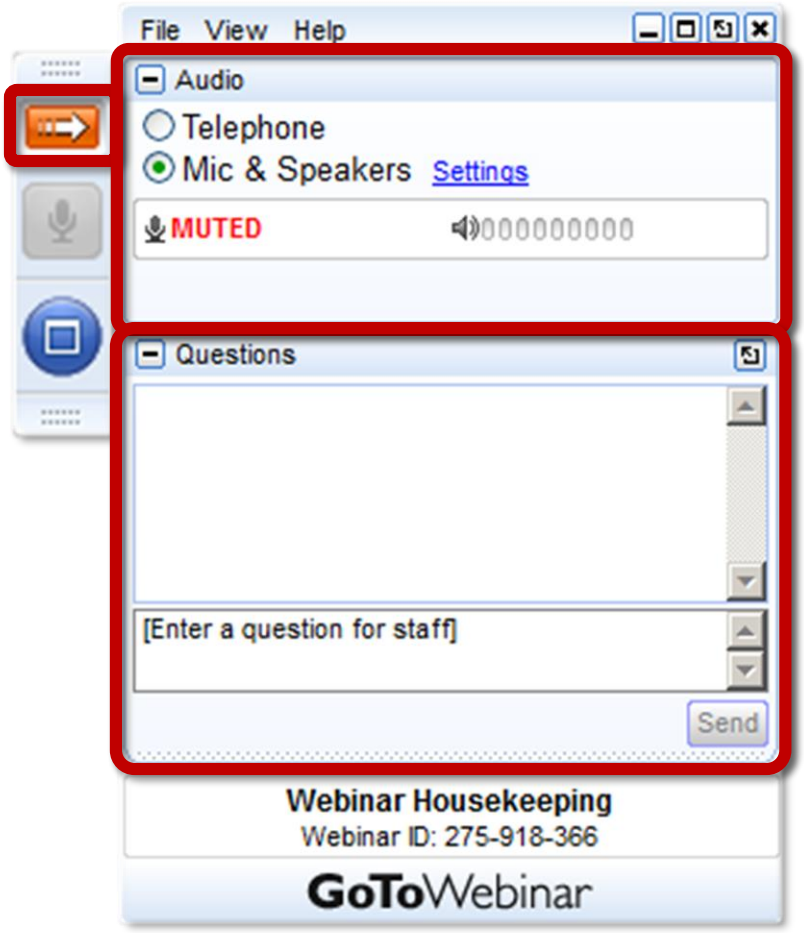
Energy Storage Technology Advancement Partnership (ESTAP) Webinar:

One Year In: Energy Storage Proves its Worth in Sterling, MA

March 7, 2018

CleanEnergy States Alliance

Housekeeping



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Energy Storage Technology Advancement Partnership (ESTAP)

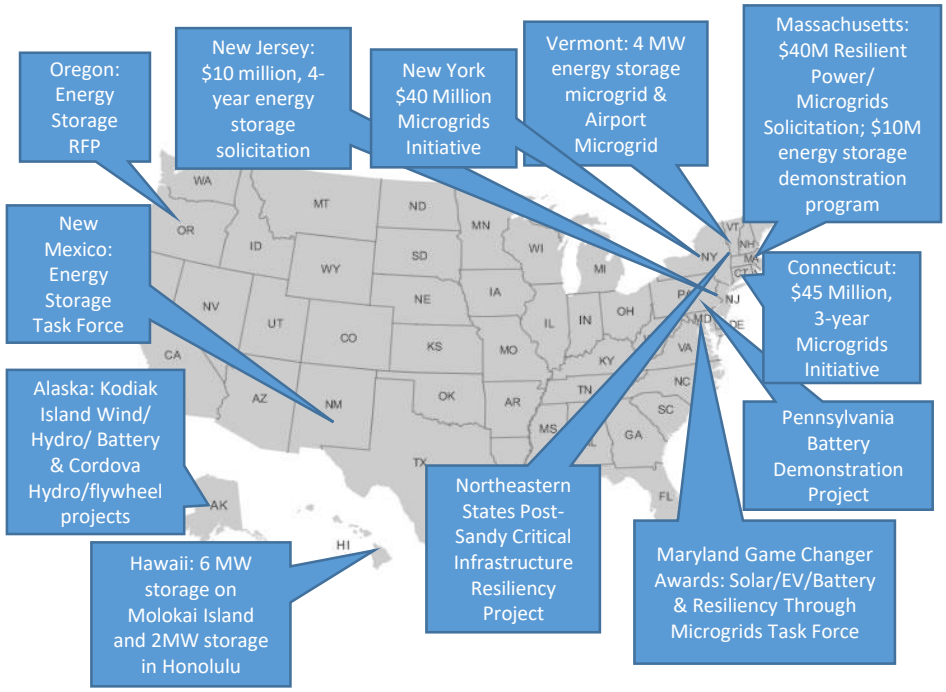
ESTAP is supported by the U.S. Department of Energy Office of Electricity and Sandia National Laboratories, and is managed by CESA.

ESTAP key activities:

1) Disseminate information to stakeholders through:
- The ESTAP listserv (>4,000 members)
- Webinars, conferences, information updates, surveys

2) Facilitate public/private partnerships at the state level to support energy storage demonstration project development.

3) Support state energy storage efforts with technical, policy and program assistance



Thank You:

Dr. Imre Gyuk
U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability

Dan Borneo
Sandia National Laboratories

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www.cesa.org/projects/energy-storage-technology-advancement-partnership

One Year In: Energy Storage Proves its Worth in Sterling, MA

- **Dr. Imre Gyuk**, U.S. Department of Energy - Office of Electricity Delivery and Energy Reliability
- **Ray Byrne**, Sandia National Laboratories
- **Sean Hamilton**, Sterling Municipal Light Department
- **Dan Borneo**, Sandia National Laboratories
- **Todd Olinsky-Paul**, Clean Energy States Alliance (Moderator)

U.S. DEPARTMENT OF ENERGY

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Sterling Municipal Light Department

CleanEnergy States Alliance

Sterling, MA: Microgrid/Storage Project

Sterling, MA, October 2016

Sterling, MA, December 2016

Sterling Municipal Light Department.

$1.5M Grant from MA Community Clean Energy Resiliency Initiative (Dept. of Energy Resources). DOE/Sandia. Clean Energy Group.

2MW/2hr storage with existing 3.4 MW PV to provide resiliency for Police HQ and Dispatch Center. Li-ion batteries provided by NEC.

Storage Economics in Action!

Description (1MW/1hr)	$
Arbitrage (buy low,sell high)	13,321
Reduced Monthly Peak	98,707
Reduced Yearly Peak	115,572
Frequency Regulation	60,476
Total	288,076

Capital cost: $1.7M/MW,
calc. potential benefits.
Simple payback: 6.7 years

R. Byrne, Sandia

2016 Dec. till **2017** Nov.
Actual Savings:

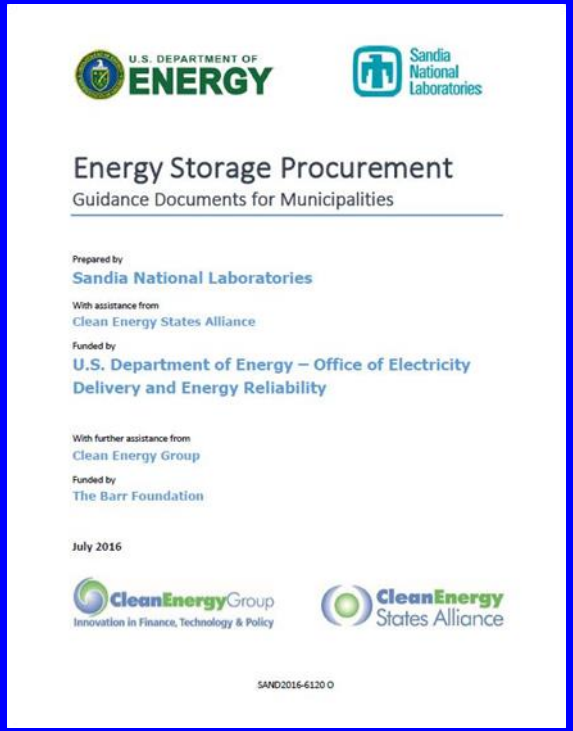
- Arbitrage $11,731
- Monthly Peaks $143,447
- Annual Peak $240,660
- Total $395,839

S. Hamilton, Sterling

Energy Storage Procurement, Guidance Document for Municipalities

Dan Borneo (Sandia)

Specific examples of the elements that should be included in a solicitation for the procurement and installation of a battery energy storage project designed to provide backup power during outages and facilitate timely cost recovery.



www.sandia.gov/ess

SAND 2016-8544

2017 GTM Grid Edge Award !

Visitors: Germany, Denmark, England, Japan, Malaysia, Taiwan

Massachusetts Follow-on Activities

- MA adopts 200 MWh utility energy storage procurement target
- ACES energy storage grants - $20 Million
- Peak Demand Reduction Grant Program - $4.68 Million

- Sterling Community Project: solar + storage

  2 MWh energy storage with 1 MW community solar

- 7 more MA municipal utilities have resiliency grants with storage

- MMWEC, which serves 42 municipal utilities in MA, now dispatching Sterling. Proposes centralized operation and dispatch services

Exceptional service in the national interest

Sandia National Laboratories



Sterling Municipal Light Department Analysis

Ray Byrne, Ph.D.

Acknowledgment: This research was funded by the Energy Storage program at the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, under the guidance of Dr. Imre Gyuk.

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Outline

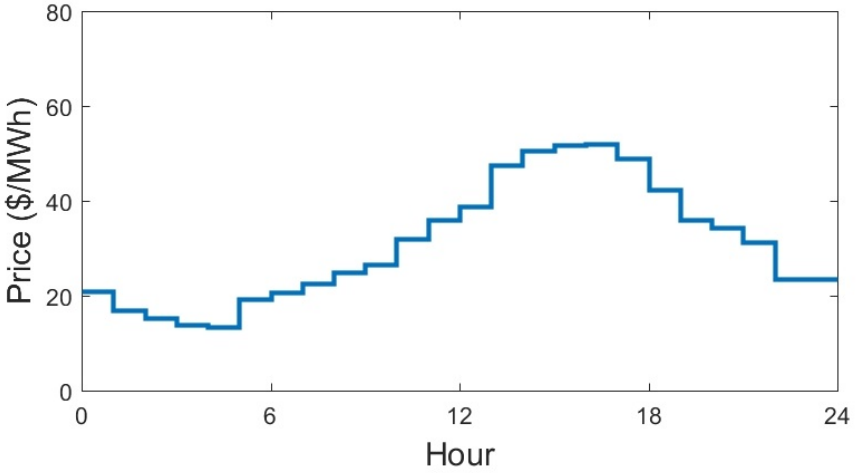
- Sterling Potential value streams:
  - Energy arbitrage
  - Reduction in monthly network load (based on monthly peak hour)
  - Reduction in capacity payments (based on annual peak hour)
  - Grid resilience
  - Frequency Regulation
- Results

Energy Arbitrage

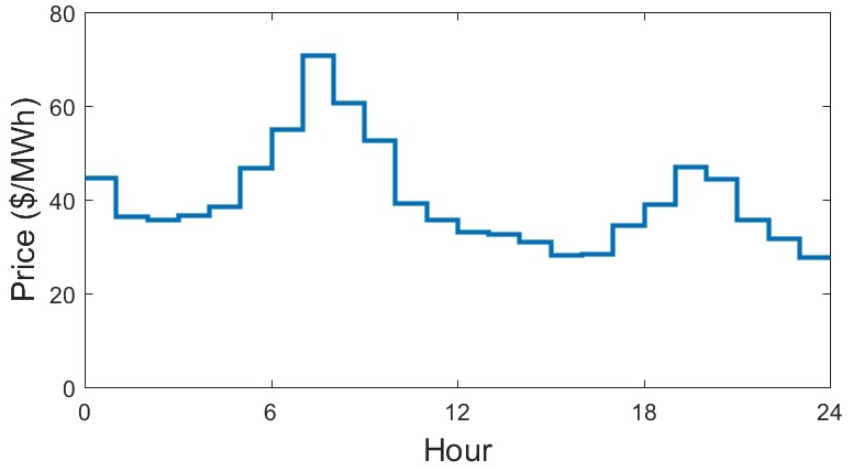
- Buy low – sell high
- Several variants
  - Day ahead market – day ahead market
  - Day ahead market – real time market
  - Renewables – day ahead market

$$\frac{LMP_H}{LMP_L} \geq \frac{1}{\eta_c}$$

- Price variations must overcome efficiency losses, η_c
  For example, 1/0.85 = 1.18



Day ahead LMP, ISO-NE node 4476, (LD.STERLING13.8), July 14, 2016



Day ahead LMP, ISO-NE node 4476, (LD.STERLING13.8), March 23, 2017

Monthly Network Load Payments

- ISO-NE employs a regional network service (RNS) payment for use of the pool transmission facilities to move electricity into or within the New England balancing authority (BA) [1]

RNS payment based on the load coincident with the monthly regional peak load hour (monthly peaks)

$$\text{RNS} = (Pool\ RNS\ Rate) \times (Monthly\ Network\ Load)$$

2 MW ~ $208K/year benefit

Year	Effective Date	Pool Transmission Facilities (PTF) Rate, $/kW-year	Pool Transmission Facilities (PTF) Rate, $/MW-month
2007	Feb 1	26.3076024	$2,192.30
2007	Jun 1	27.9071165	$2,325.59
2008	Mar 1	27.8897124	$2,324.14
2008	Jun 1	43.7560841	$3,646.34
2008	Dec 1	43.8466113	$3,653.88
2009	Jun 1	59.9470029	$4,995.58
2010	Jun 1	64.8268400	$5,402.24
2011	Jun 1	63.8737400	$5,322.81
2011	Oct 1	61.5059000	$5,125.49
2012	Jun 1	72.7458500	$6,062.15
2013	Jan 1	75.3400300	$6,278.34
2013	Jun 1	85.2171500	$7,101.43
2014	Jun 1	90.2789700	$7,523.25
2014	Oct 1	88.7655200	$7,397.13
2014	Nov 1	87.3466600	$7,278.89
2015	Jun 1	98.7014700	$8,225.12
2016	Jun 1	104.1004100	$8,675.03

[1] ISO-NE, “New England control area transmission services and ISO-NE open access transmission tariff: General business practices. section 2: Pool PTF rate, pool RNS rate and schedule 1 rate; and an overview of the RNS or T/Out service application process,” http://www.iso-ne.com/, 2016.

Forward Capacity Market Payments

- ISO-NE has implemented a Forward Capacity Market (FCM) because electricity markets alone do not provide adequate financial incentives to invest in new generation

$$\text{Capacity Payment} = (Capacity\ Load\ Obligation) \times (Net\ Regional\ Clearing\ Price)$$

- Capacity load obligation determined on the annual peak day/hour identified by ISO-NE

SMLD CAPACITY CLEARING PRICE, ISO-NE. PERIOD RUNS FROM JUNE 1 TO MAY 31.

Year	Price ($/kW-Month)
2010-2011	$4.254
2011-2012	$3.119
2012-2013	$2.535
2013-2014	$2.516
2014-2015	$2.855

Year	Price ($/kW-Month)
2015-2016	$3.129
2016-2017	$3.150
2017-2018	$7.025
2018-2019	$9.551
2019-2020	$7.030

$$FCM_{savings} \approx (FCM\ obligation) * LOAD_{reduction}/LOAD_{peak}$$

2016 data, 2 MW ~ $(12*3.129*32968)*2000/24039 = $102,989

Grid Resilience

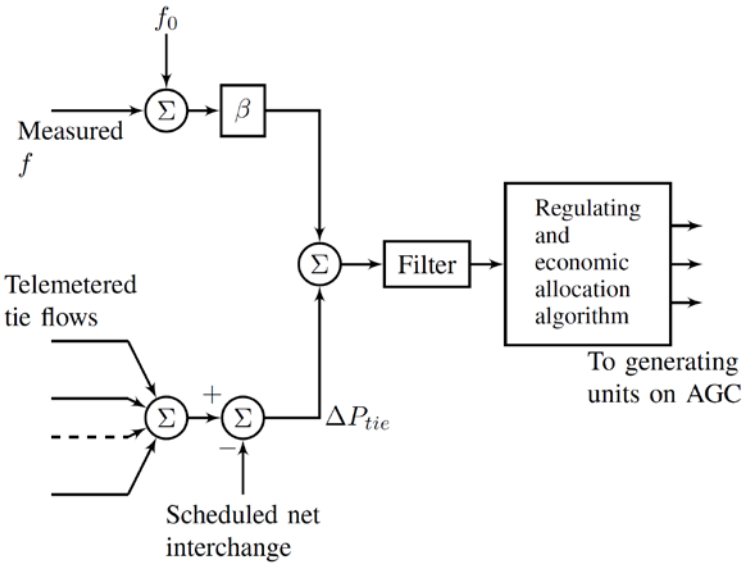
- The benefit of “backup power” is equivalent to the “Value of Lost Load”
- Value of lost load (VOLL) – the average cost to customers per megawatt-hour of unserved load when they are disconnected during involuntary load shedding [1].
- VOLL typically calculated using:
  - Market prices (indirect method)
  - Surveys (direct method)

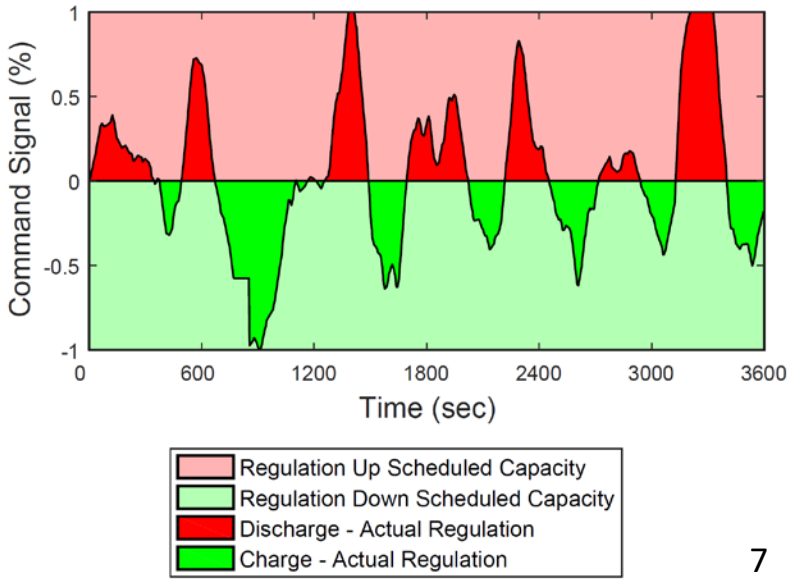
- Sterling application: backup power for first responders (police and dispatch center)
- Closest data point available in the literature: public administration (small commercial and industrial)
- Likely understates the value to Sterling

[1] Steven Stoft, Power System Economics: Designing Markets for Electricity, Wiley-IEEE Press, 2002.

Frequency Regulation

- Frequency regulation is an ancillary service to maintain grid frequency
- Different market implementations:
  - Regulation up/Regulation down, e.g., CAISO, ERCOT
  - Regulation (bidirectional), e.g., ISO-NE, PJM, MISO
- Automatic generation signal sent every 2-4 seconds
- FERC Order 755 – pay for performance: performance score and mileage payment
- Some ISOs have a “fast” AGC signal (e.g., PJM)





Arbitrage Results

Sandia National Laboratories

Arbitrage optimization results using historical data

year	0.25 MW	0.50 MW	0.75 MW	1.00 MW	1.25 MW	1.50 MW	1.75 MW	2.00 MW
2010	$12,764	$23,175	$29,973	$33,927	$36,456	$38,234	$39,553	$40,781
2011	$11,226	$19,514	$25,129	$28,931	$31,545	$33,411	$34,861	$36,229
2012	$11,082	$19,340	$24,581	$27,920	$30,208	$31,934	$33,331	$34,653
2013	$18,211	$30,725	$39,285	$44,726	$48,619	$51,595	$54,005	$56,276
2014	$21,101	$35,596	$46,527	$53,851	$58,924	$62,748	$65,788	$68,657
2015	$14,261	$24,387	$31,328	$35,892	$39,019	$41,353	$43,201	**$44,935**

Results for a 4MWh system (Sterling is a 2MW, 3.9 MWh system)

Arbitrage + Regulation Results

Sandia National Laboratories

Arbitrage + regulation optimization results using historical data

year	0.25 MW	0.50 MW	0.75 MW	1.00 MW	1.25 MW	1.50 MW	1.75 MW	2.00 MW
2010	$21,035	$40,330	$57,198	$72,545	$86,921	$100,764	$113,962	$127,145
2011	$20,117	$38,304	$55,137	$70,945	$85,923	$100,439	$114,363	$128,254
2012	$19,003	$36,275	$52,131	$66,934	$81,068	$94,795	$107,985	$121,140
2013	$33,543	$63,214	$90,902	$116,897	$141,655	$165,611	$188,550	$211,402
2014	$48,052	$92,768	$136,190	$178,293	$219,068	$259,011	$297,818	$336,578
2015	$54,209	$106,790	$158,784	$210,338	$261,461	$312,242	$362,471	$412,683

Results for a 4MWh system (Sterling is a 2MW, 3.9 MWh system)

Arbitrage + Regulation + RNS + FCM

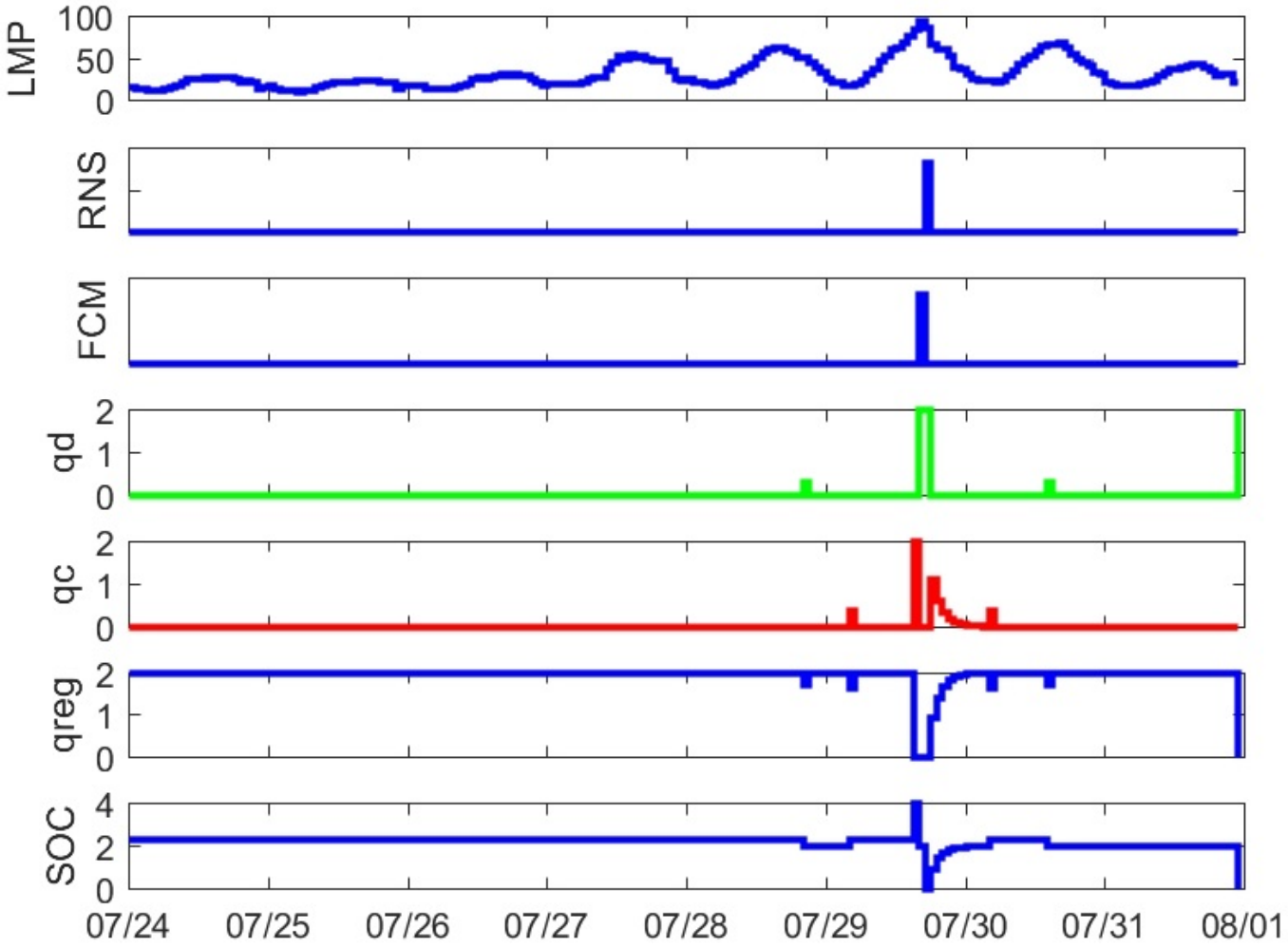
Sandia National Laboratories

Arbitrage + regulation + RNS + FCM optimization results using historical data

year	0.25 MW	0.50 MW	0.75 MW	1.00 MW	1.25 MW	1.50 MW	1.75 MW	2.00 MW
2012	$45,129	$88,528	$130,501	$171,417	$211,653	$251,458	$290,688	$329,882
2013	$63,146	$122,418	$179,672	$235,229	$289,495	$342,908	$395,242	$447,486
2014	$79,724	$156,100	$231,170	$304,914	$377,324	$448,790	$518,937	$589,032
2015	$87,839	$174,029	$259,632	$344,788	$429,462	$513,712	$597,296	$680,849

Results for a 4MWh system (Sterling is a 2MW, 3.9 MWh system)

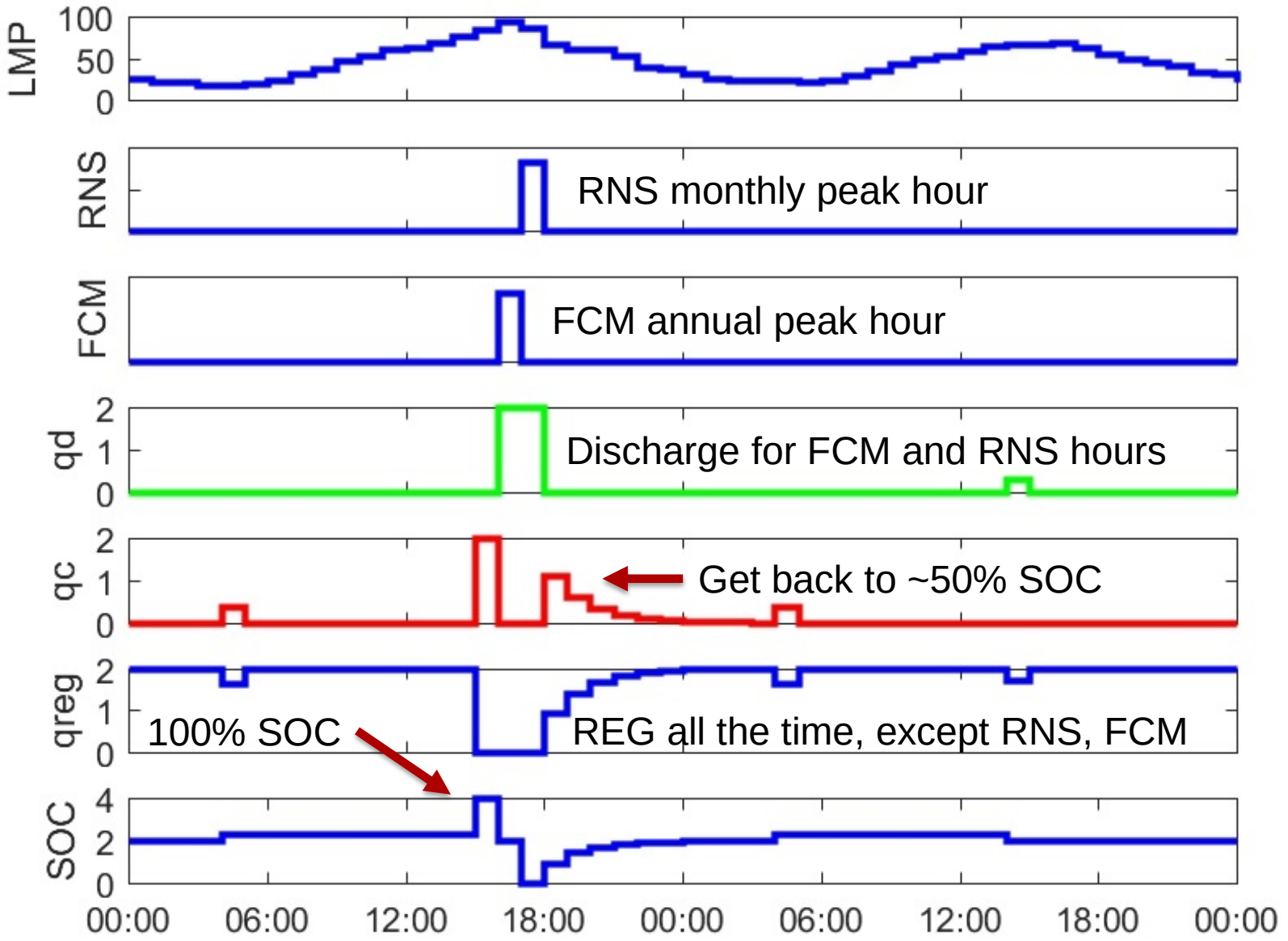
Optimization Results – Typical Week



- Last week of July 2015
- Annual and monthly peaks
- Spend the majority of the time at 50% SOC performing frequency regulation
- Charge up to 100% SOC in hour prior to FCM peak
- Discharge for two consecutive hours (FCM and RNS peak)
- Return to 50% SOC and continue performing frequency regulation
- Note minimal arbitrage (qc, qd)
- Assumes an energy neutral (with losses) regulation signal

2 MW, 4 MWh system

Optimization Results – Typical Day



Grid Resilience

- Grid Resilience - SMLD has identified 10kW as the critical load

	Capacity			
	1 MWh	2 MWh	3 MWh	4 MWh
Days	4.167	8.333	12.5	16.667
VoLL	$40,819	$81,629	$122,448	$163,267

- VOLL from [1], public administration (small commercial and industrial)
- Likely understates the value to Sterling because it involves first responders (police and fire)

[1] M. J. Sullivan, M. Mercuriov, and J. Schellenberg, "Estimated value of service reliability for electric utility customers in the United States," Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, Tech. Rep. LBNL-2132E, June 2009.

Summary

- Arbitrage is more synergistic with other peak shaving applications
- Analysis shows significant potential revenue from:
  - FCM savings
  - RNS savings
  - Frequency regulation
- For more information, please refer to:

R. H. Byrne, S. Hamilton, D. R. Borneo, T. Olinsky-Paul, and I. Gyuk, "The value proposition for energy storage at the Sterling Municipal Light Department," proceedings of the 2017 IEEE Power and Energy Society General Meeting, Chicago, IL, July 16-20, 2017, pp. 1-5. DOI: 10.1109/PESGM.2017.8274631

- Available at www.sandia.gov\ess

http://www.sandia.gov/ess/docs/journals/SterlingMA_2017PES_SAND2017-1093.pdf

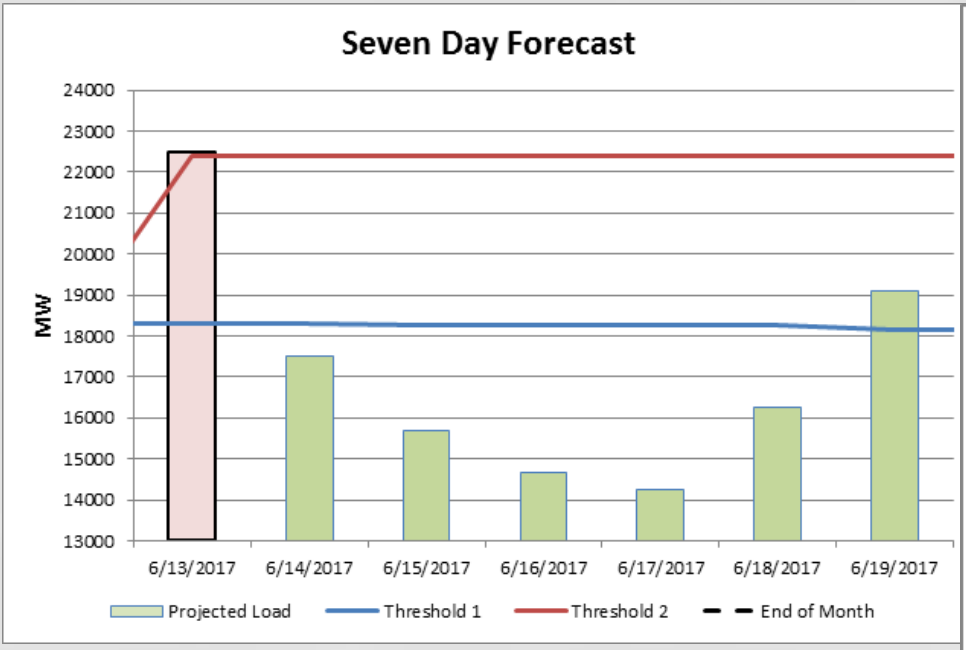
Sterling Municipal Light Dept.

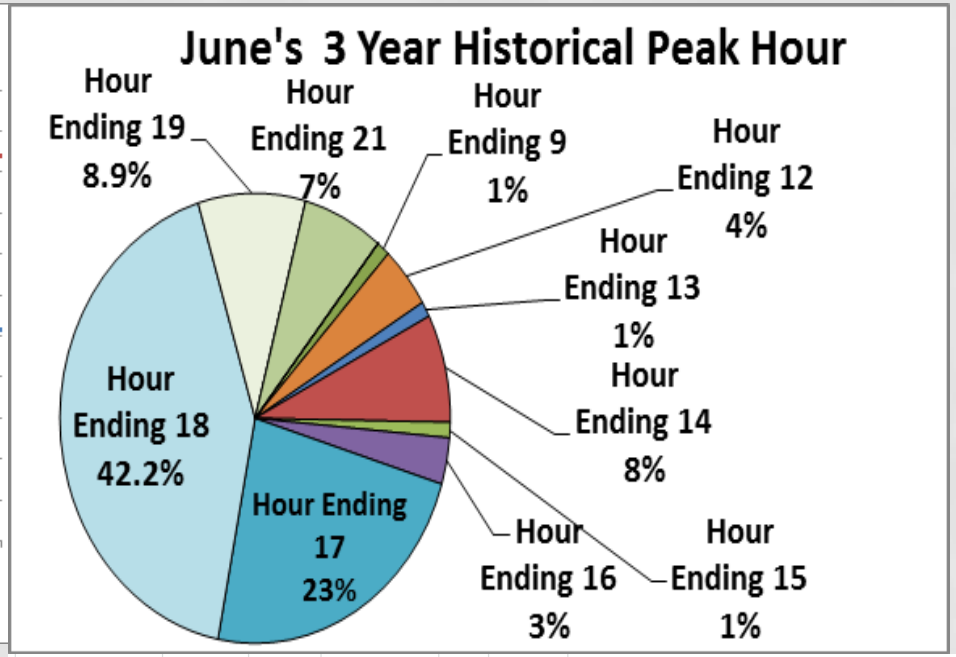
Energy Storage Proves its Worth Sterling, MA

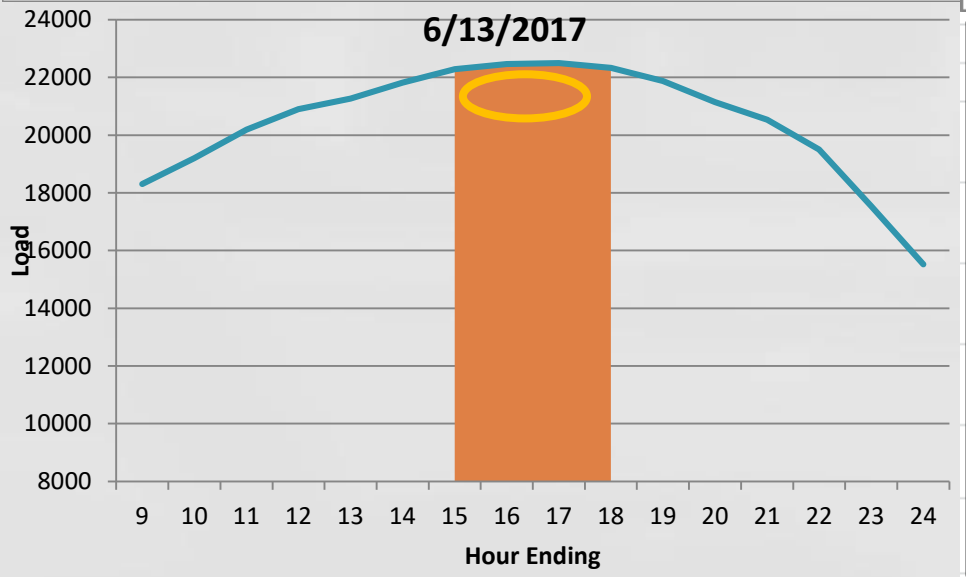
March 7, 2018

Sean Hamilton, General Manager


NEC



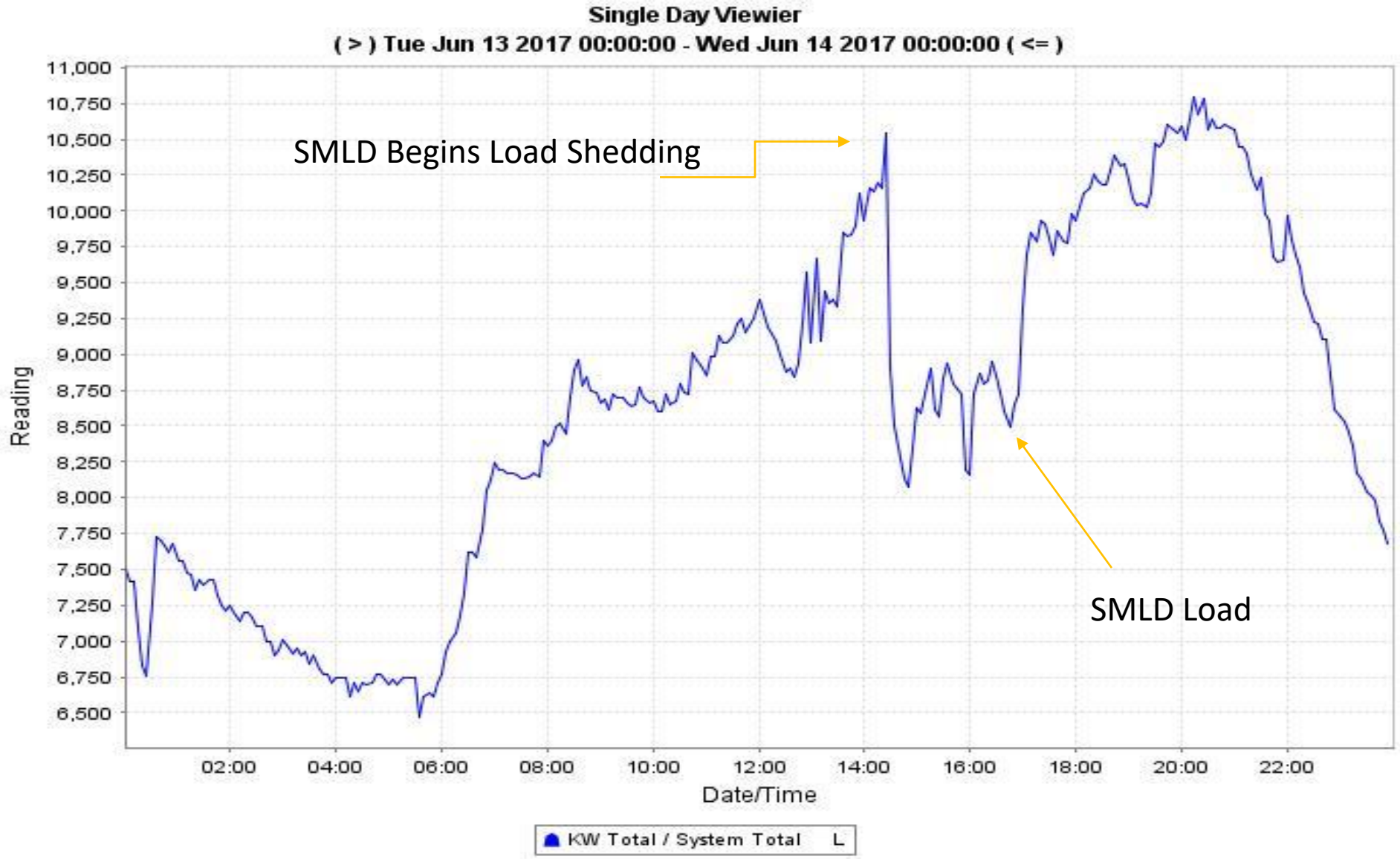




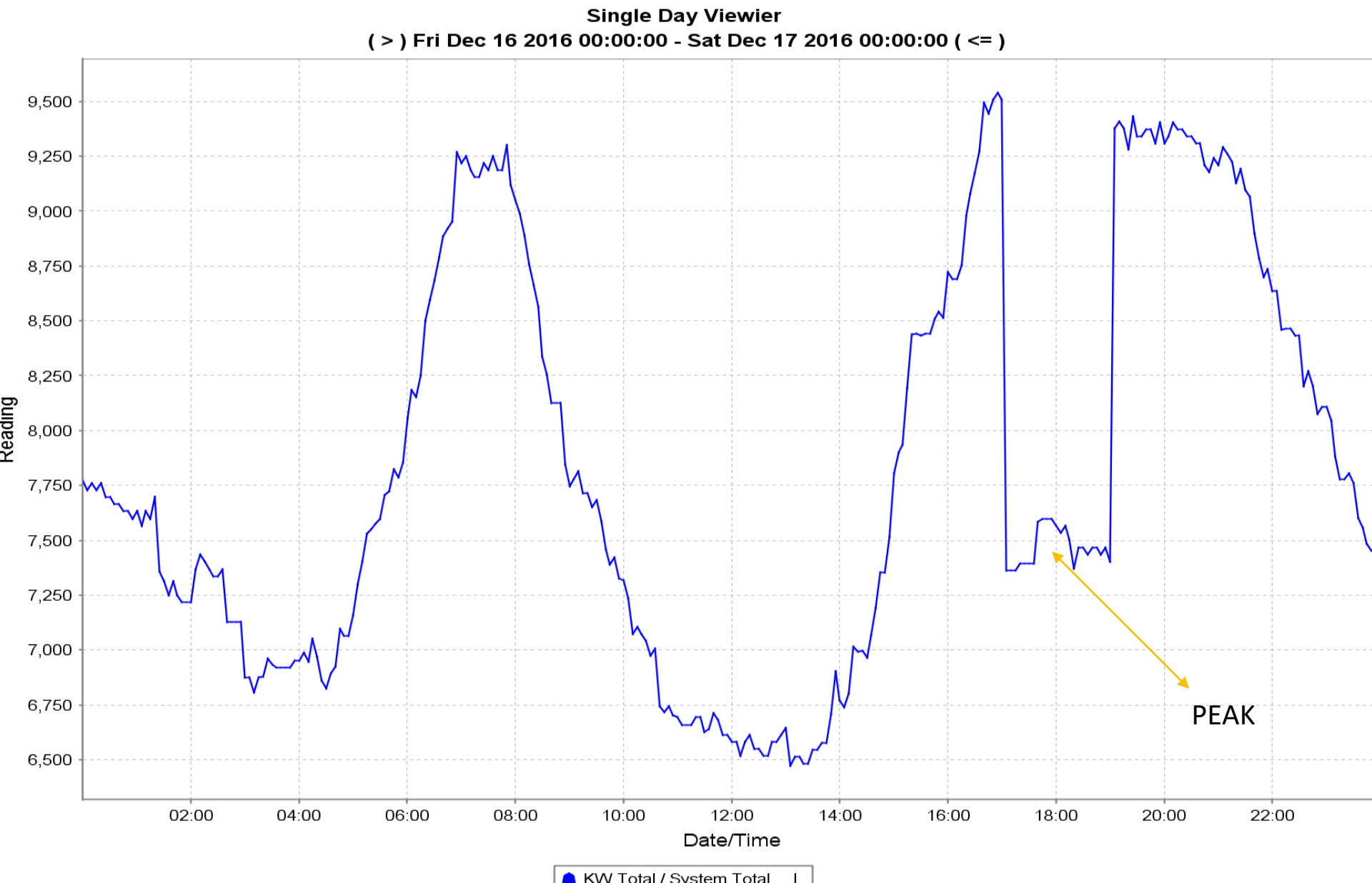
Alert Ratings Explained

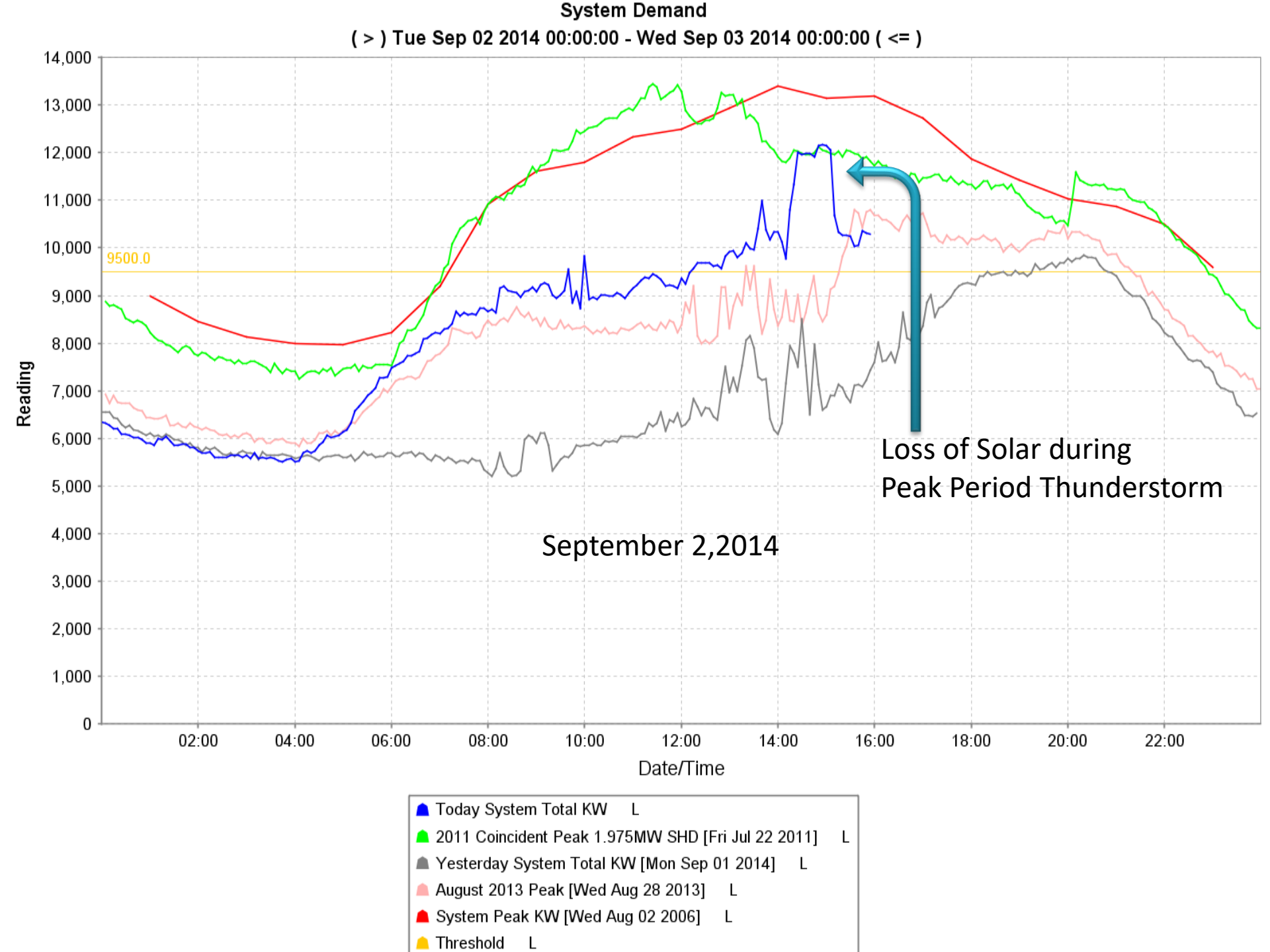
Rating	Definition	Advice
0	Projected peak is below the threshold by greater than 1,000 MW.	Take no action. This will not be the peak day.
1	Projected peak is below the threshold by an amount between 500 and 1,000 MW.	Take no action. Barring a dramatic miss by ISO this will not be the peak day.
2	Projected peak is below the threshold by an amount less than 500 MW.	Be aware of the situation. Peak load is approaching threshold, but will most likely not be the peak.
3	Projected peak is above the threshold by an amount less than 500 MW.	Send alert. Today has a chance of being the peak day
4	Projected peak is above the threshold by an amount between 500 and 1,000 MW.	Send alert. There is a strong chance that today will be the peak day
5	Projected peak is above the threshold by an amount greater than 1,000 MW.	Send alert. There is an extremely high probability that today will be the peak day.

June 13,2017 – ISO-NE Peak Day



Began Construction 10-12-2016
Reduces RNS Peak on 12-16-2016




System Demand
(>) Tue Sep 02 2014 00:00:00 - Wed Sep 03 2014 00:00:00 (<=)
14,000
13,000
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12:00
14:00
16:00
18:00
20:00
22:00
Date/Time
Loss of Solar during
Peak Period Thunderstorm
September 2,2014
Today System Total KW L
2011 Coincident Peak 1.975MW SHD [Fri Jul 22 2011] L
Yesterday System Total KW [Mon Sep 01 2014] L
August 2013 Peak [Wed Aug 28 2013] L
System Peak KW [Wed Aug 02 2006] L
Threshold L

Costs To Install*

>Engineering	$116,212.03
>Feasibility Study	$7,000.00
>BESS (with Inverter)	$2,034,075.00
>Other Equipment	$154,129.61
>Labor Incl- Line Crew	$76,390.25
>Legal	$62,725.06
>Testing/Commissioning	$11,293.95
>Admin, Ops Supv ,GM, Acct.	$80,893.14
	$2,542,719.04

* Does not include Optional Substation Communication or Relay Panel upgrades

Value of Battery Energy Storage

- **Grid Resiliency - Police and Dispatch Center**
- **Smoothing Intermittent Resources**
- **Regional Network Service (RNS) -Monthly Peak**
  - **Captured 10/13 monthly peaks for a value of $162,107k**
- **Capacity Load Obligation Payments – Annual Peak**
  - **Captured Annual Peak (June 13) for a value of $244,460**
- **Energy Arbitrage-Value to Date $13k, 36 Round Trip Operations**
- **Frequency Regulation-Not Participating in this Market**

Source: The Value Proposition for Energy Storage for Sterling Municipal Light Department

Author Dr. Raymond Byrne, Sandia National Laboratories. www.energysterling.com

Hour	HUB	WCMA	NEMA	SEMA	CT	RI	NH	VT	ME	
1	21.69	**21.71**	21.77	21.8	21.73	21.66	17.59	20.72	20.22	
2	27.99	**28.05**	28.07	28.09	28.13	28.03	23.68	26.9	18.56	
3	19.58	**19.64**	19.62	19.64	19.7	19.61	15.61	18.97	8.79	
4	-20.34	**-20.42**	-20.34	-20.41	-20.56	-20.4	-22.66	-19.88	-24.92	
5	-1.47	**-1.47**	-1.45	-1.47	-1.49	-1.47	-4.69	-1.41	-1.72	
6	-27.02	**-27.11**	-26.99	-27.1	-27.29	-27.07	-29.29	-26.43	-25.34	
7	-12.31	**-12.35**	-12.3	-12.35	-12.45	-12.33	-15.36	-12.09	-11.64	
8	24.56	**24.63**	24.63	24.56	24.73	24.38	20.21	23.93	23.43	
9	29.65	**29.72**	29.78	29.6	29.76	29.31	25.32	28.52	28.08	
10	44.57	**45.69**	92.48	44.55	44.8	43.77	41.17	42.35	41.5	
11	55.62	**56.37**	85.02	55.49	56.08	54.73	53.17	52.45	51.73	
12	50.48	**51.66**	100.33	50.29	51.08	49.65	45.22	47.19	46.36	
13	51.72	**52.72**	101.46	51.79	51.93	50.98	41.36	46.41	41.24	
14	61.28	**61.89**	101.88	61.73	60.75	60.72	43.48	51.33	40.87	
15	179.66	**175.9**	201.92	186.82	166.37	181.76	26.15	87.78	-11.88	
16	278.24	**274.75**	299.81	285.15	266	278.96	132.98	187.31	88.79	
17	285.91	**282.35**	330.31	293.65	271.68	286.84	124.29	185.3	79.3	
18	389.17	**387.24**	674.03	401.56	363.88	390.88	122.59	222.72	49.49	
19	219.73	**217.88**	342.98	226.43	205.44	220.51	77.09	129.77	26.21	
20	159.24	**156.44**	173.21	164.06	149.17	159.87	62.95	99.91	37.33	
21	141.67	**139.13**	172.38	146.17	132.1	142.37	48.44	84.47	23.3	
22	78.47	**77.66**	124.87	80.75	73.68	78.67	28.82	48.64	7.15	
23	29	**28.49**	40.16	30.14	26.84	29.32	3.55	14.79	-7.99	
24	25.52	**25.36**	26.46	25.93	24.94	25.56	15.74	20.89	15.83	
AVG	88.03	**87.33**	122.09	90.29	83.63	88.18	37.39	57.52	23.53	
On Peak AVG	129.94	**128.91**	180.95	133.3	123.39	130.17	56.05	84.55	35.31	
Off Peak AVG	4.21	**4.18**	4.36	4.27	4.09	4.2	0.08	3.46	-0.03	
Charged	.333/hr									**$10.41**
Discharged	**1.2/hr**									**$1,096.36**
Net										**$ 1,085.95**
RNS Savings	Annual	Monthly	KW @ peak	value						
	103.86	8.667	1200	10400						**$10,400.40**
Savings										$11,486.35

Arbitrage May 18,2017

Resiliency Benefits
2 MW / 3.9 MWh Battery Energy Storage System

- BESS provides power up to 12 days
- BESS located in main substation
- Substation 2,300’ from critical facility
- Separate circuit for BESS and CF
- MicroGrid capable with solar
- Live test performed April 27, 2017

UTILITY ENERGY STORAGE RANKINGS

TOP 10 ANNUAL WATTS-PER-CUSTOMER

1	Sterling Municipal Light Department	533 Watts-per-customer
2	Glasgow EPB	248 W/C
3	Imperial Irrigation District	198 W/C
4	American Samoa Power Authority	109 W/C
5	Indianapolis Power & Light Company	42 W/C
6	Duke Energy Ohio	23 W/C
7	Maui Electric	17 W/C
8	San Diego Gas & Electric	12 W/C
9	Green Mountain Power	8 W/C
10	Commonwealth Edison, an Exelon Company	6 W/C

SEPA Solar Watts Per Customer Comparison

SEPA 2013

Rank	Utility	W/C
1	Sterling Municipal Light Dept (MA).	831
2	San Diego Gas & Electric Company (CA)	461
3	Silicon Valley Power/City of Santa Clara (CA)	427
4	Arizona Public Service (AZ)	368
5	Hawaiian Electric Company, Inc. (HI)	329
6	Pacific Gas and Electric Company (CA)	281
7	Hawaii Electric Light Company (HI)	182
8	Maui Electric Company Ltd (HI)	178
9	Kauai Island Utility Cooperative (HI)	167
10	Imperial Irrigation District (CA)	159

SEPA 2015

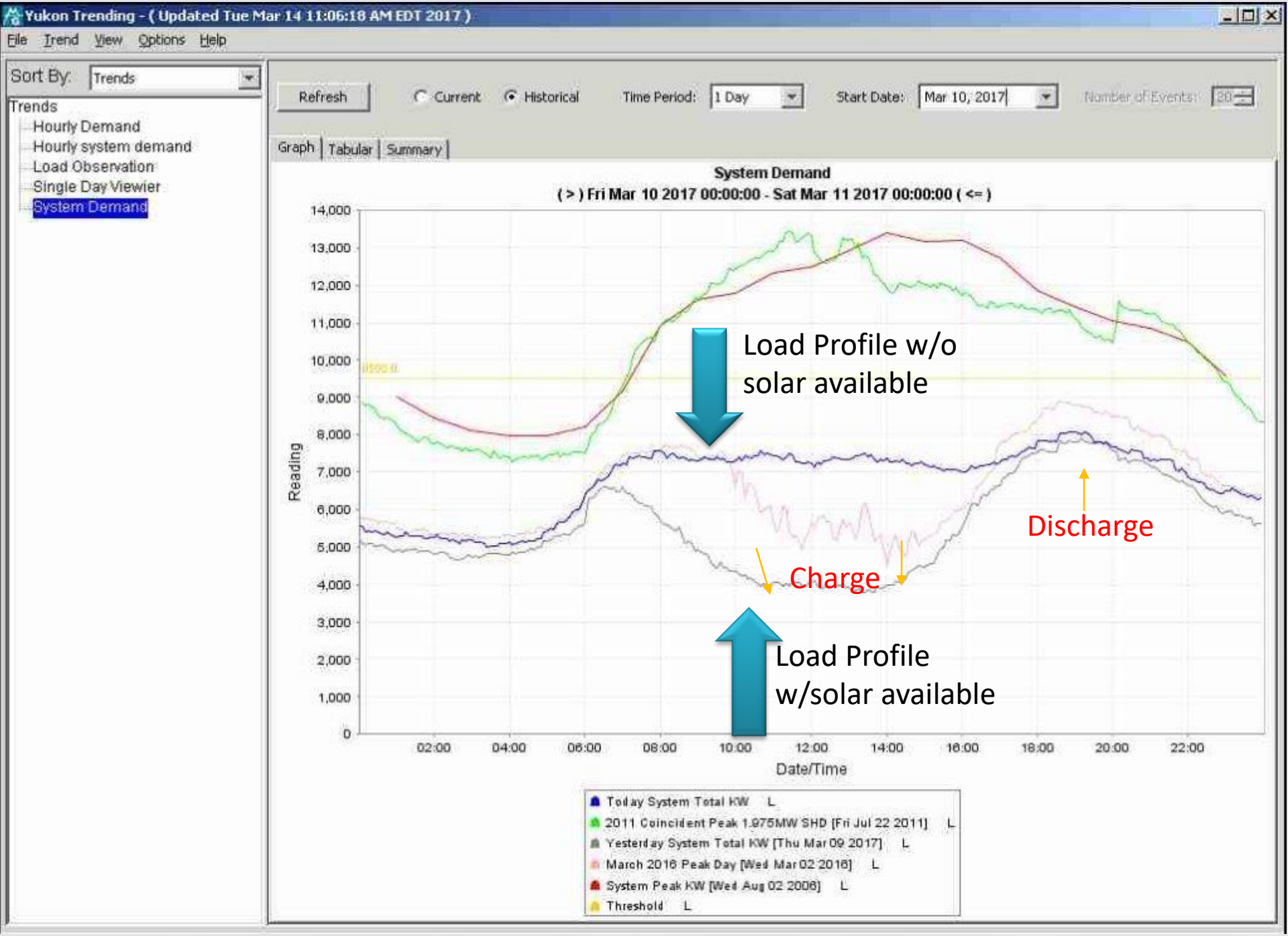
1	Village of Minster (OH)	2,104
2	City of Palo Alto Utilities (CA)	1,846
3	Roseville Electric Utility (CA)	1,416
4	Carey Municipal Electric Utility (OH)	1,351
5	Vineland Municipal Electric Utility (NJ)	1,318
6	Ashburnham Municipal Light Plant (MA)	1,079
7	Sterling Municipal Light Department (MA)	848
8	Imperial Irrigation District (CA)	750
9	Guam Power Authority (GU)	710
10	Silicon Valley Power (CA)	613

Sterling Municipal Light Department

New Project

1 MW Community Solar with
1 MW / 2 MWh Battery Storage

- Battery charging achieved with solar
- Shift low cost solar to peak periods
- Allows residents access to solar, otherwise unavailable
- Peak shaving benefits shared with all ratepayers
- Program subscription roll out expected April 2018


Yukon Trending - (Updated Tue Mar 14 11:06:18 AM EDT 2017)
File Trend View Options Help
Sort By: Trends
Trends
Hourly Demand
Hourly system demand
Load Observation
Single Day Viewier
System Demand
Refresh
Current
Historical
Time Period: 1 Day
Start Date: Mar 10, 2017
Number of Events: 20
Graph
Tabular
Summary
System Demand
(>) Fri Mar 10 2017 00:00:00 - Sat Mar 11 2017 00:00:00 (<=)
Reading
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Date/Time
Load Profile w/o solar available
Discharge
Charge
Load Profile w/solar available
Today System Total KW L
2011 Coincident Peak 1.975MW SHD [Fri Jul 22 2011] L
Yesterday System Total KW [Thu Mar 09 2017] L
March 2016 Peak Day [Wed Mar 02 2016] L
System Peak KW [Wed Aug 02 2006] L
Threshold L

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- SMLD Commissioners/Operations - For their support of this project
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- Todd Olinsky-Paul – Project Director of CEG and CESA
- MMWEC - Market Observation, Peak Forecasting and Operations
- Scott Reynolds, OPM and Mike Barrett, PLM, Design Engineering
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Webinar Archive:
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ESTAP Listserv:
bit.ly/EnergyStorageList

CleanEnergy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Upcoming Webinars

The Status of State Grid Modernization Efforts

Friday, March 9 , 1-2pm ET

Valuing Resilience: Exploring the Role of Solar+Storage in Grid Outages

Wednesday, March 14, 1-2pm ET

New Financing Options for Solar+Storage in Low-Income Communities

Thursday, March 29, 1-2pm ET

Issues before FERC and the Potential Implications for Renewables and Energy Storage

Thursday, April 26, 1-2pm ET

Read more and register at www.cesa.org/webinars