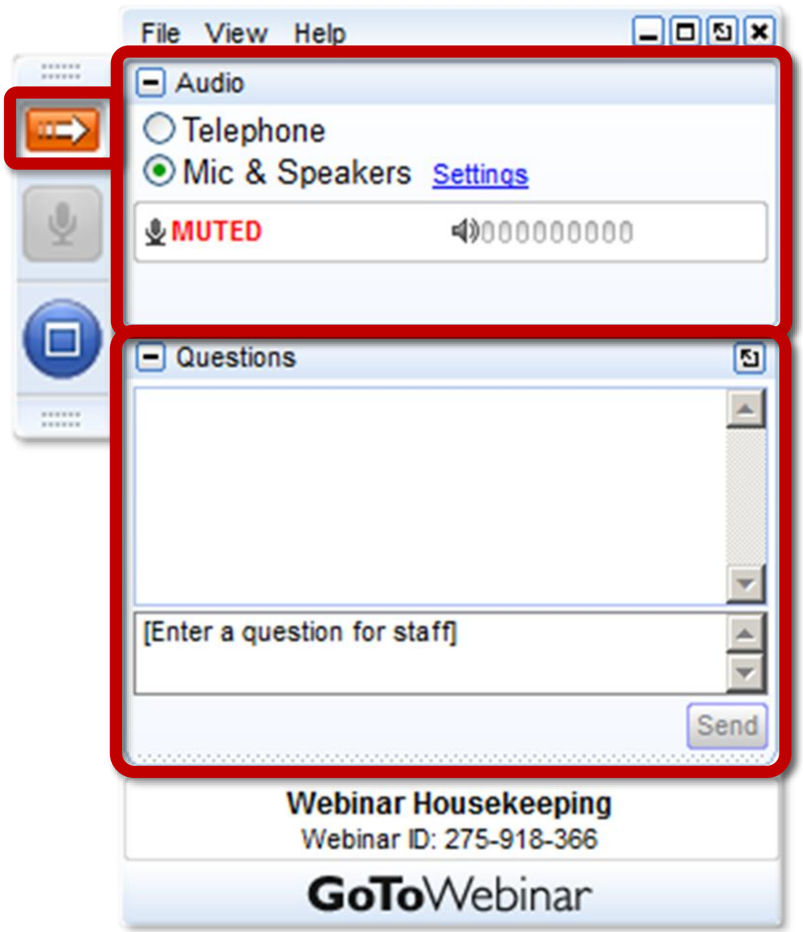
Energy Storage Technology Advancement Partnership (ESTAP) Webinar:

The Value Proposition for Energy Storage at the Sterling Municipal Light Department

April 27, 2017

Hosted by Todd Olinsky-Paul
ESTAP Project Director
Clean Energy States Alliance

Housekeeping



Use the red arrow to open and close your control panel

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- Choose Mic & Speakers to use VoIP
- Choose Telephone and dial using the information provided

Submit questions and comments via the Questions panel

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Thank You:

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

Dan Borneo
Sandia National Laboratories

CleanEnergy States Alliance
Sandia National Laboratories
U.S. DEPARTMENT OF ENERGY

ESTAP is a project of CESA

Clean Energy States Alliance (CESA) is a non-profit organization providing a forum for states to work together to implement effective clean energy policies & programs:

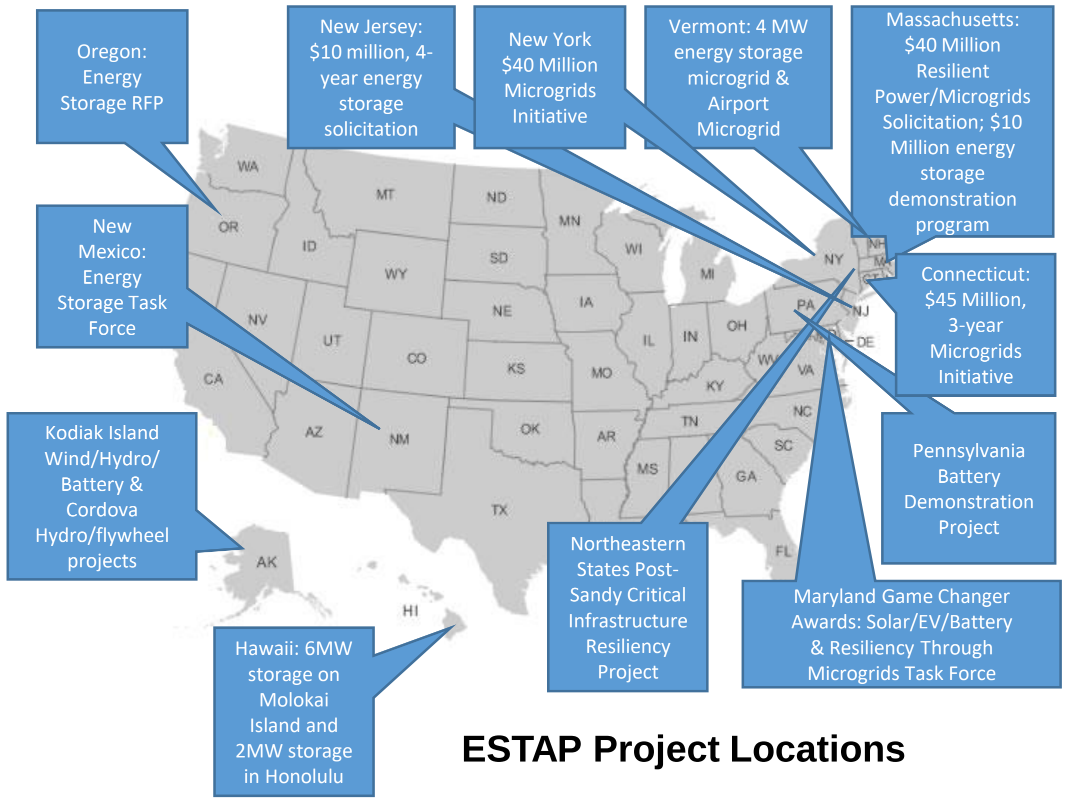
State & Federal Energy Storage Technology Advancement Partnership (ESTAP) is conducted under contract with Sandia National Laboratories, with funding from US DOE.

ESTAP Key Activities:

1. Disseminate information to stakeholders
   - ESTAP listserv >3,000 members
   - Webinars, conferences, information updates, surveys.

2. Facilitate public/private partnerships to support joint federal/state energy storage demonstration project deployment

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



ESTAP Project Locations

Clean Energy States Alliance

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

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ESTAP

Project Director: Todd Olinsky-Paul

Contact: Todd Olinsky-Paul, Todd@cleanegroup.org

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The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by CESA, that aims to accelerate the deployment of electrical energy storage technologies in the U.S.

The project's objective is to accelerate the pace of deployment of energy storage technologies in the United States through the creation of technical assistance and co-funding partnerships between states and the U.S. Department of Energy.

ESTAP conducts two key activities:

1) Disseminate information to stakeholders through:

- The ESTAP listserv (>2,000 members)
- Webinars, conferences, information updates

NEW RESOURCES

October 14, 2015

Resilience for Free: How Solar+Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Net Cost

By Clean Energy Group

September 30, 2015

Webinar Slides: Energy Storage Market Updates, 9.30.15

UPCOMING EVENTS

December 16, 2015

ESTAP Webinar: State of the U.S. Energy Storage Industry,

More Events

LATEST NEWS

November 30, 2015

Massachusetts Takes the Lead on Resilient

Panelists

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

U.S. DEPARTMENT OF ENERGY

Sterling Municipal Light Department

Sandia National Laboratories

CleanEnergy States Alliance

Energy Storage

Developing Value Propositions through Grid Scale Validation

IMRE GYUK, DIRECTOR,
ENERGY STORAGE RESEARCH, DOE-OE

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.

DOE-OE providing funds and technical support towards expansion to 2MW/3MWh

- Backup for police station / dispatch center (resilience)
- Cost savings for reducing transmission capacity (monthly peak)
- Revenues from capacity charges to ISO (yearly peak)
- Arbitrage and Frequency Regulation
- Integration of intermittent PV

Making the Microgrid Pay for itself !!
An approach developed with Green Mountain Power at the Rutland, VT Project

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

simple payback: 6.7 years

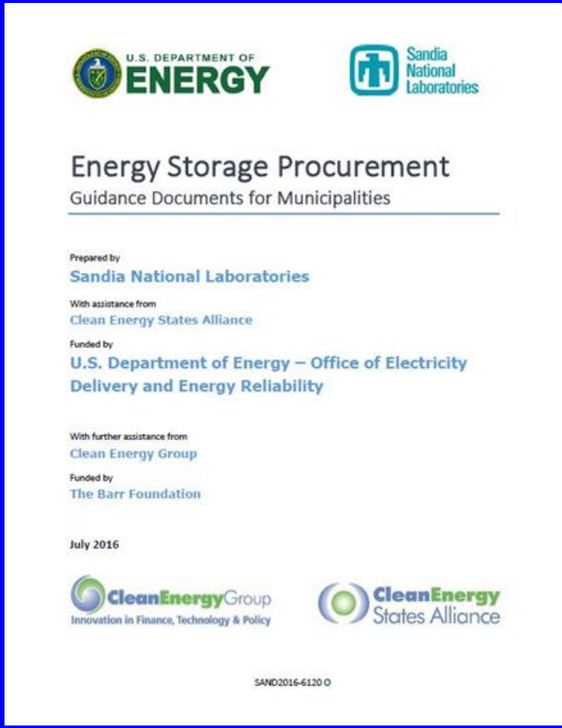
R. Byrne

- ✓ **2016** December
- ✓ **2017** February
- ✓ **2017** March
- ✓ **2017** April

S. Hamilton

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.


U.S. DEPARTMENT OF ENERGY
Sandia National Laboratories

Energy Storage Procurement
Guidance Documents for Municipalities

Prepared by
Sandia National Laboratories

With assistance from
Clean Energy States Alliance

Funded by
U.S. Department of Energy – Office of Electricity Delivery and Energy Reliability

With further assistance from
Clean Energy Group

Funded by
The Barr Foundation

July 2016

CleanEnergyGroup
Innovation in Finance, Technology & Policy
CleanEnergy States Alliance

SAND2016-6120 O

www.sandia.gov/ess
SAND 2016-8544

2017 GTM Grid Edge Award !

Other DOE-OE Storage Projects:

Eugene, OR, Water & Energy Board

Resiliency Microgrid
500kW Storage + 125kW PV + Diesel gen sets
at 2 aggregated sites

Cordova, AK, Study with ACEP

Hydropower Smoothing

Kona, HI, with NELHA and HELCO

Enabling more solar PV
100kW/500kWh of V/V Batteries

Orca Island with OPALCO

WA Clean Energy Fund
500kW/4 hour V/V system for resilience

With new Technologies
Cost will go down, Safety and Reliability will increase

With every successful Project the Value Propositions will continue to increase!

More jobs will be created!!

Sterling Municipal Light Dept.

The Value Proposition for Energy Storage

April 27, 2017

Sean Hamilton General Manager

Value of Energy Storage

- **Grid Resiliency-Police and Dispatch Center**
- **Smoothing Intermittent Resources- 3.4 MW Solar**
- **Regional Network Service (RNS) -Monthly Peak**
- **Capacity Load Obligation Payments –Annual Peak**
- **Energy Arbitrage**
- **Frequency Regulation**

- Source: The Value proposition for Energy Storage for Sterling Municipal Light Department
- Author Dr. Raymond Byrne, Sandia National Laboratories. www.energysterling.com

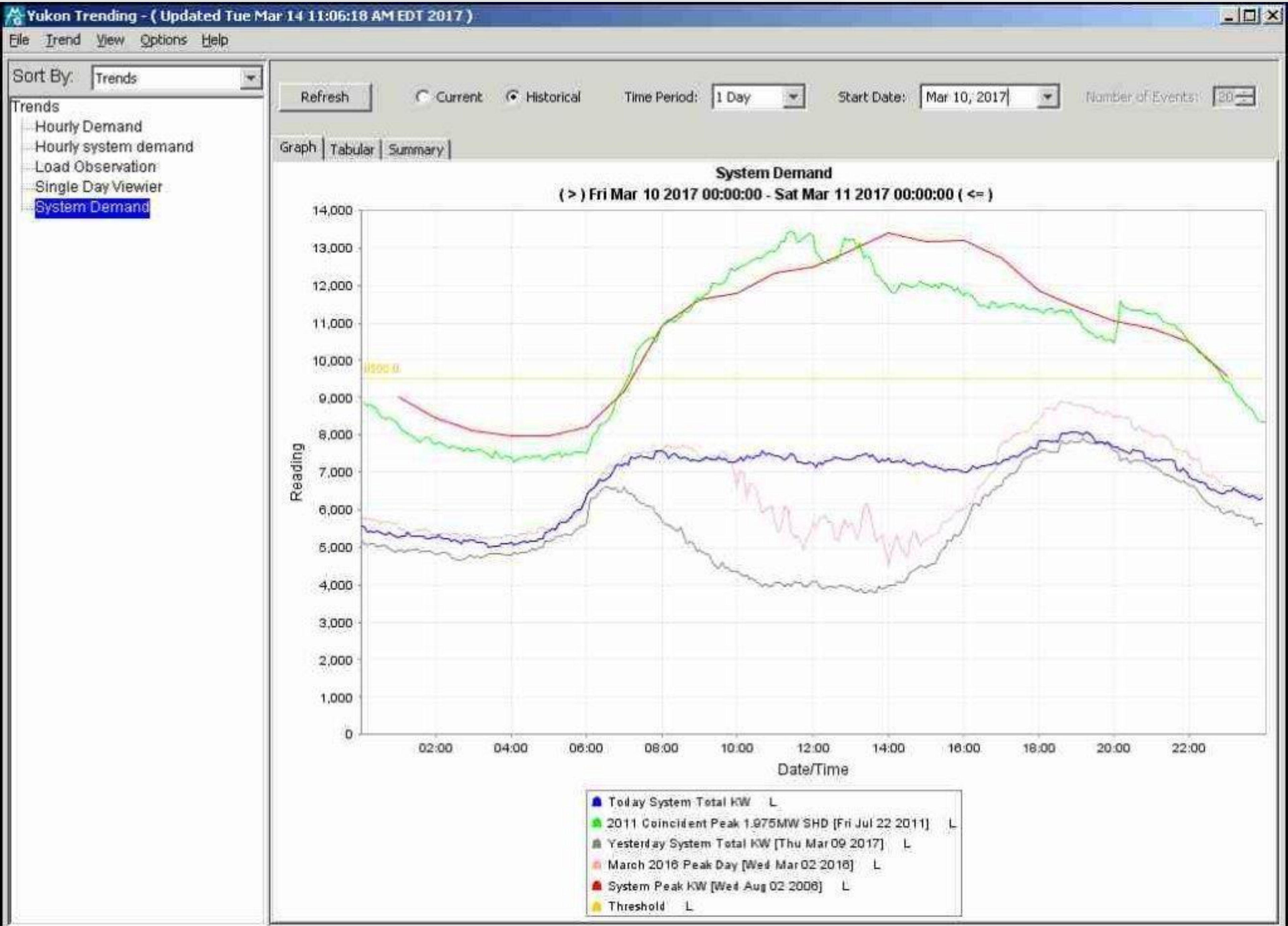
SEPA Solar Watts Per Customer Comparision

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

	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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Hourly system demand
Load Observation
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Time Period: 1 Day
Start Date: Mar 10, 2017
Number of Events:
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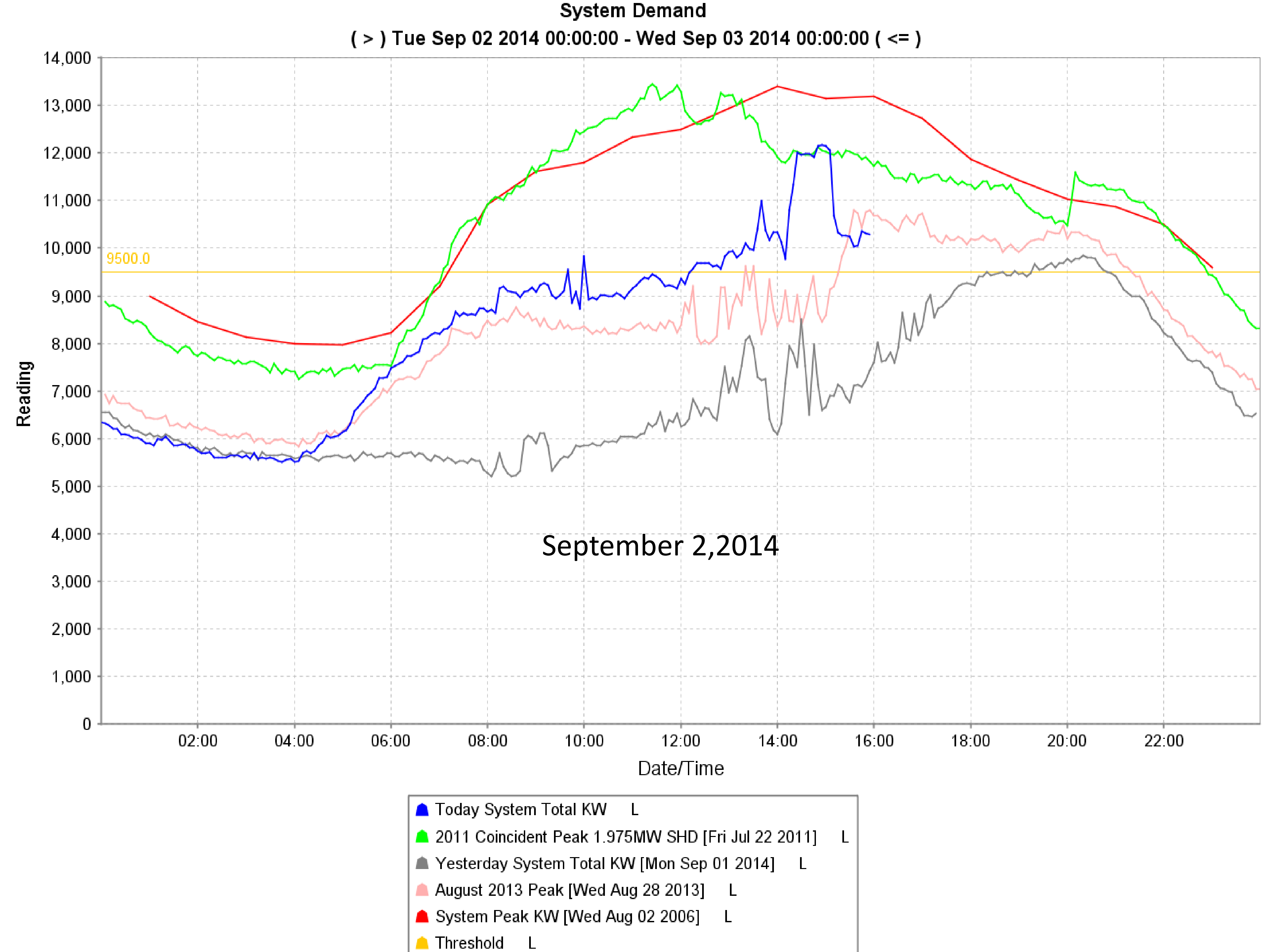
16:00
18:00
20:00
22:00
Date/Time
Today System Total KW L
2011 Coincident Peak 1.975MW SHD [Fri Jul 22 2011] L
Yesterday System Total KW [Thu Mar 09 2017] L
March 2016 Peak Day [Wed Mar 02 2016] L
System Peak KW [Wed Aug 02 2006] L
Threshold L


System Demand
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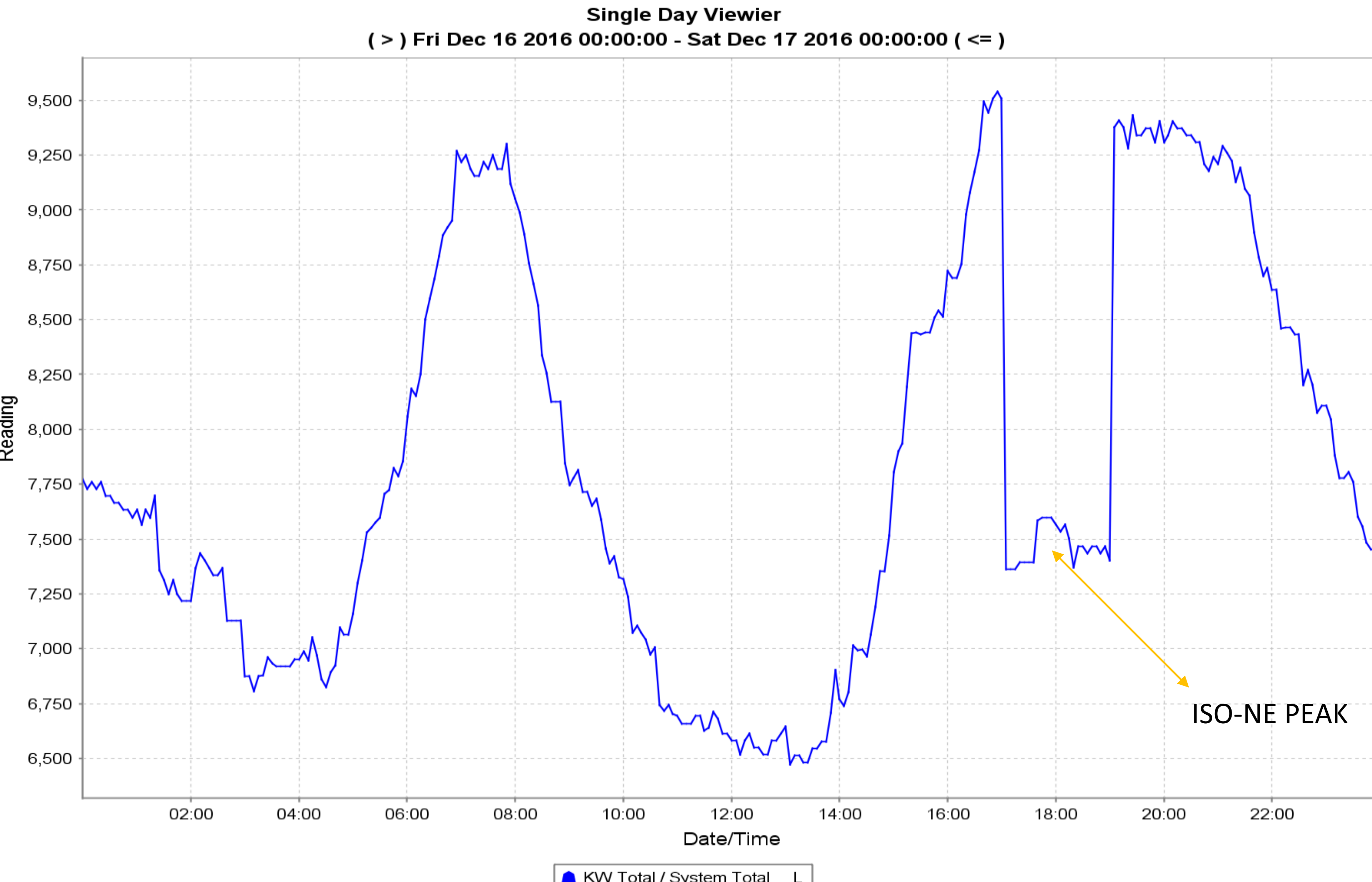
Date/Time
September 2,2014
Today System Total KW L
2011 Coincident Peak 1.975MW SHD [Fri Jul 22 2011] L
Yesterday System Total KW [Mon Sep 01 2014] L
August 2013 Peak [Wed Aug 28 2013] L
System Peak KW [Wed Aug 02 2006] L
Threshold L

Final Real-Time Locational Marginal Prices ($/MWh) 9/2/2014

Hour	HUB	WCMA	NEMA	SEMA	CT	RI	NH	VT	ME
1	44.23	44.35	44.48	44.03	44.40	44.39	43.85	43.75	41.88
2	38.15	38.31	38.22	37.84	38.36	38.17	37.74	37.75	36.11
3	32.98	33.11	33.01	32.68	33.09	32.96	32.67	32.54	31.54
4	28.23	28.34	28.26	28.01	28.26	28.19	28.02	27.90	27.13
5	28.06	28.19	28.07	27.83	28.17	27.97	27.89	27.81	26.98
6	32.97	33.10	32.98	32.67	33.11	33.09	32.86	32.82	31.77
7	37.33	37.46	37.49	37.03	37.51	37.24	37.44	37.29	36.38
8	40.87	40.99	41.07	40.62	41.05	40.90	41.01	40.86	39.96
9	35.01	35.09	35.25	36.10	35.06	41.63	35.25	34.96	34.33
10	45.85	45.99	46.13	46.51	46.09	50.20	46.07	45.92	44.34
11	73.81	74.12	74.15	73.39	74.69	73.55	74.11	74.15	71.31
12	89.80	90.11	90.35	89.45	93.48	89.51	90.14	89.86	86.67
13	185.70	186.25	187.11	185.44	190.47	185.53	186.15	184.95	178.01
14	554.71	555.62	560.77	555.12	558.00	555.55	555.69	551.95	530.00
15	206.54	206.72	209.37	207.47	308.93	207.60	206.72	205.66	196.51
16	70.45	70.57	71.51	70.86	158.68	70.91	70.15	70.67	65.38
17	86.23	86.34	87.48	86.72	168.94	86.71	85.96	86.14	80.60
18	133.90	134.22	135.05	134.18	174.45	134.14	133.38	133.73	126.21
19	72.92	73.14	73.35	72.90	107.74	72.81	72.65	73.38	68.10
20	75.16	75.35	75.60	75.14	82.61	75.08	75.14	75.41	71.28
21	74.36	74.62	74.61	74.20	75.75	73.96	74.14	74.76	70.18
22	55.07	55.27	55.32	54.86	55.76	54.56	54.81	54.91	52.16
23	38.60	38.75	38.82	38.36	39.02	38.21	38.48	38.42	36.99
24	54.55	54.76	54.98	54.15	55.00	54.01	54.41	54.12	52.48
AVG	88.98	89.20	89.73	88.98	104.53	89.45	88.95	88.74	84.85
On Peak AVG	114.94	115.20	116.00	115.08	138.17	115.68	114.99	114.73	109.50
Off Peak AVG	37.06	37.20	37.19	36.78	37.24	37.00	36.86	36.75	35.53


NEC

Began Construction October 12,2016
Operating and Captures Peak on 12-16-2016




Micro Grid Capable
Police & Dispatch Facility
Chocksett Substation
Wiles Rd 2 MW solar array
George-Peeso-Rd
Northeast Blvd
Chocksett Rd
Pratts Junction Rd
Albright Rd
Village Ln
Sandy Ridge Rd
Wiles Rd
Redstone Hill Rd
12
62
© 2014 Google
Google
Imagery Date: 9/20/2010 42°27'00.86" N 71°44'14.78" W elev 434 ft

2017 TOP 10 SEPA

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

Special Thanks to :

- SMLD Commissioners/Operations - For their support of this project.
- Town of Sterling - For their continued support .
- Judith Judson – MA DOER Commissioner.
- Dr. Imre Gyuk - U.S. Dept of Energy, Energy Storage Program Director.
- Sandia National Laboratories - Daniel Borneo PE., Dr. Raymond Byrne.
- Todd Olinsky-Paul - Director of CEG and CESA.
- The Barr Foundation.
- MMWEC - Market Analysis.
- Scott Reynolds, Reynolds Engineering LLC, Owners Project Manager.
- Mike Barrett, PLM, Design Engineering
- Jared Carpenter, Jim Frawley-Grant Technical Information.

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 U.S. Department of Energy Office of Electricity Energy Storage Program, under the guidance of Dr. Imre Gyuk.

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

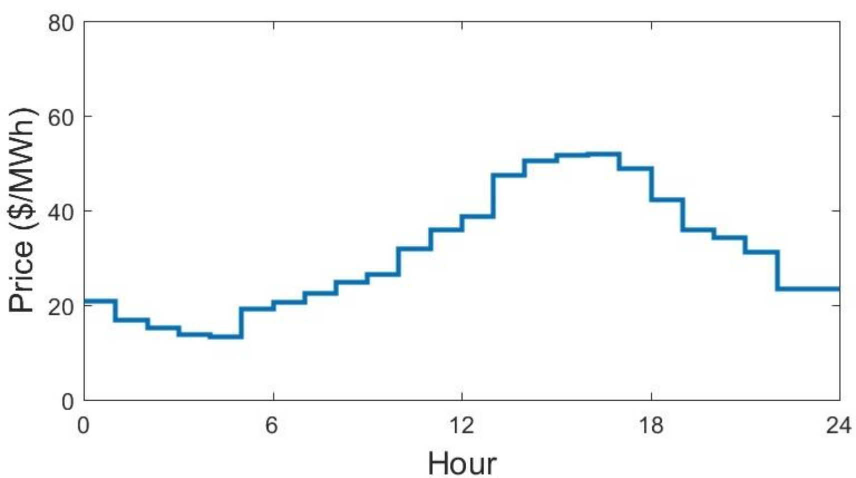
- Sterling Potential value streams:
  - Energy arbitrage
  - Reduction in monthly network load (based on monthly peak hour)
  - Reduction in capacity payments (based on annual peak hour)
  - Grid resilience
  - Frequency Regulation
- Formulation of the revenue maximization problem
  - Sandia approach for evaluating potential revenue
  - Energy storage model
  - Historical data
  - Solvers
- Results

Energy Arbitrage

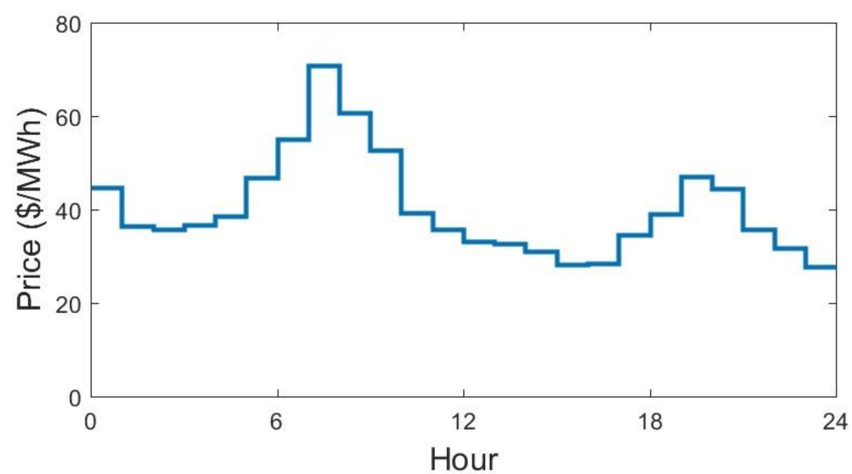
- Buy low – sell high
- Several variants
  - Day ahead market – day ahead market
  - Day ahead market – real time market
  - Renewables – day ahead market

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

- 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

2016 data, 2 MW ~ $2000*12*3.15 = $75,600

Grid Resilience

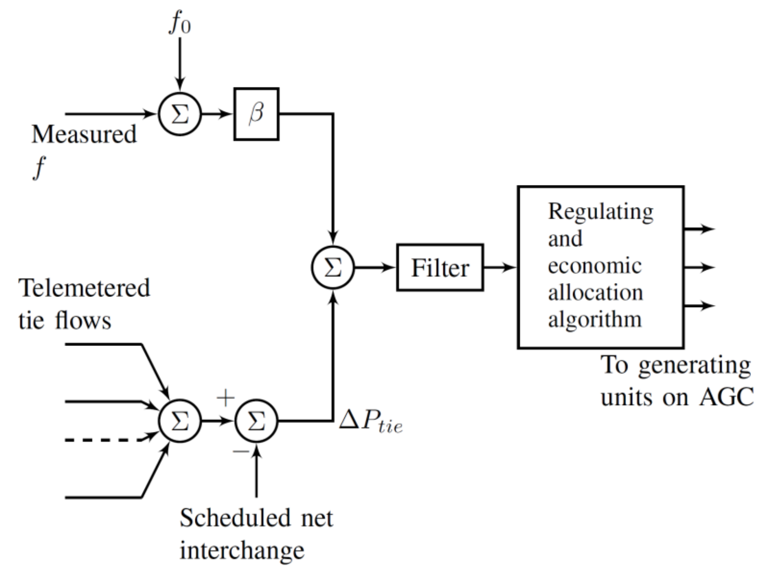
- The benefit of “backup power” is equivalent to the “Value of Lost Load”
- Value of lost load (VOLL) – the average cost to customers per megawatt-hour of unserved load when they are disconnected during involuntary load shedding [1].
- VOLL typically calculated using:
  - Market prices (indirect method)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

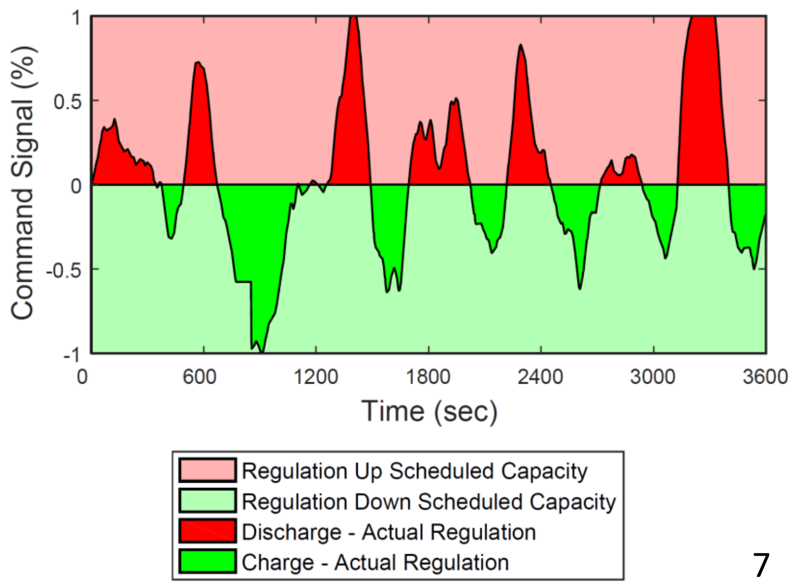
- Sterling application: backup power for first responders (police and dispatch center)
- Closest data point available in the literature: public administration (small commercial and industrial)
- Likely understates the value to Sterling

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

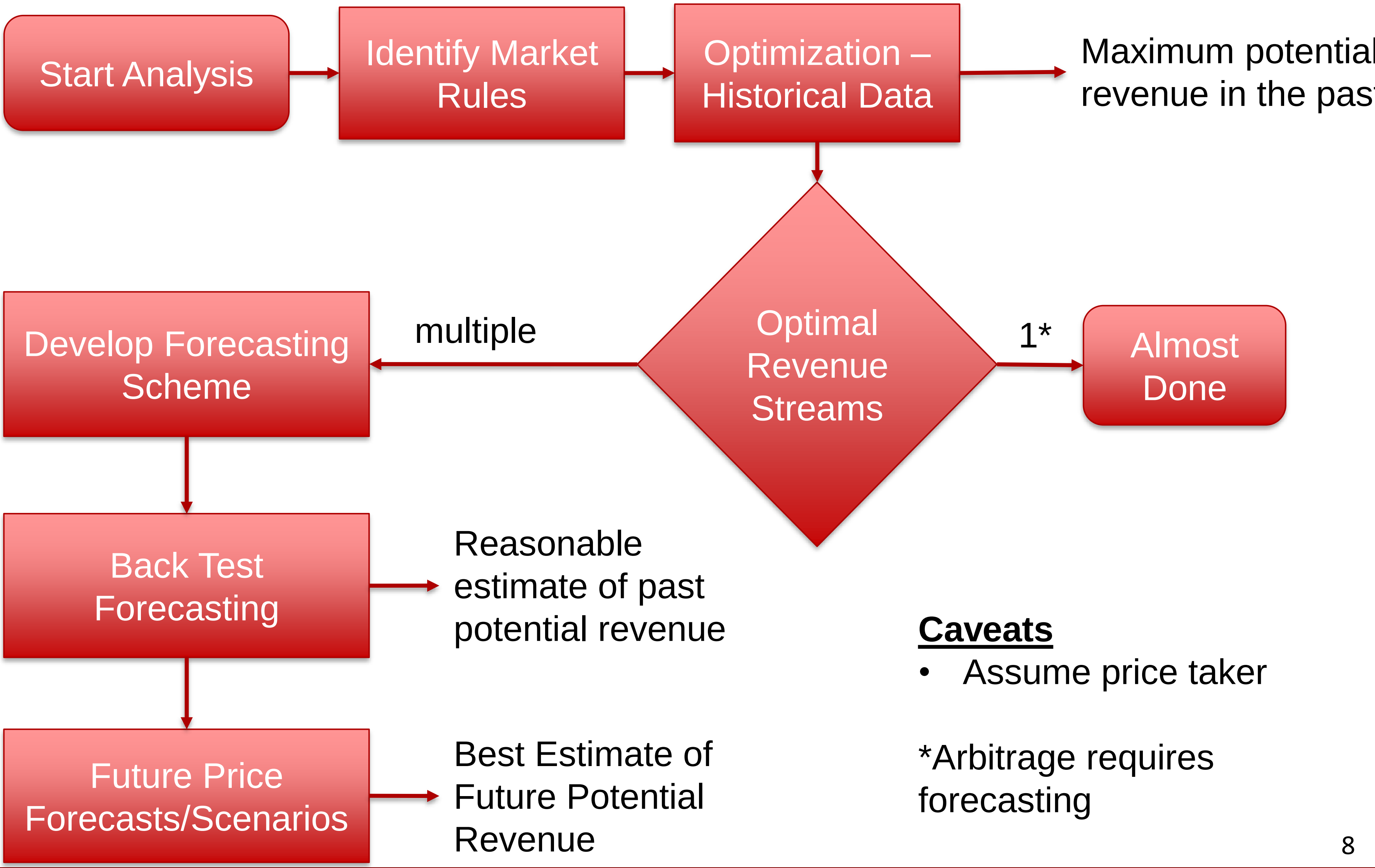
Frequency Regulation

- 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)





Maximizing Revenue – Market Area



<u>Caveats</u>

- Assume price taker

*Arbitrage requires forecasting

Storage Model - Arbitrage

- Assume price insensitive to supply (if not -> production cost modeling)
- Typically use 1 hour data
- Energy storage model – arbitrage

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D \; \forall t \in T$$

T	number of time periods in optimization.
S_t	state-of-charge at the end of period t (MWh).
q_t^D	energy discharged in period t (MWh).
q_t^R	energy charged in period t (MWh).
γ_s	storage efficiency over one period (%).
γ_c	conversion efficiency (%).

Storage Model - Arbitrage

- Constraints on:
  - Total capacity
  - Maximum hourly charge/discharge quantity

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D \ \forall t \in T$$

$$0 \leq S_t \leq \bar{S}, \ \forall t \in T$$
$$0 \leq q_t^R \leq \bar{q}^R, \ \forall t \in T$$
$$0 \leq q_t^D \leq \bar{q}^D, \ \forall t \in T$$

Storage Model – Arbitrage + Regulation

- Assume price insensitive to supply (if not -> production cost modeling)
- Typically use 1 hour data
- Energy storage model – arbitrage + regulation

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_t^{RD} q_t^{REG} - \gamma_t^{RU} q_t^{REG}$$

S_t	state of charge at time t, (MWh)
γ_s	storage efficiency (losses over one time period)
γ_c	conversion efficiency
q_t^R	recharge quantity at time t, (MWh)
q_t^D	discharge quantity at time t, (MWh)
γ_t^{RD}	fraction of regulation down bid called at time t
γ_t^{RU}	fraction of regulation up bid called at time t
q_t^{REG}	accepted regulation quantity at time t, (MWh)

Storage Model – Arbitrage + Regulation

- Constraints on:
  - Total capacity
  - Maximum hourly charge/discharge quantity

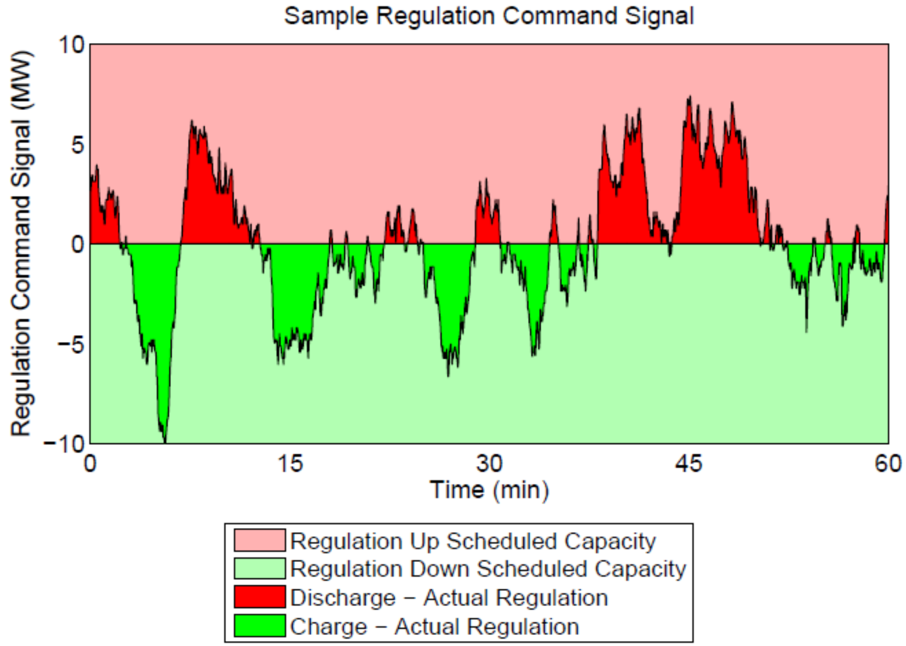
$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_t^{RD} q_t^{REG} - \gamma_t^{RU} q_t^{REG}$$

$$q_t^{REG} \leq S_t \leq \bar{S} - q_t^{REG}, \ \forall t \in T$$
$$0 \leq q_t^R + q_t^{REG} \leq \bar{q}^R, \ \forall t \in T$$
$$0 \leq q_t^D + q_t^{REG} \leq \bar{q}^D, \ \forall t \in T$$

Even though we assume "perfect knowledge", we are conservative – the state-of-charge must be capable of handling any frequency regulation signal (full amount in either direction)

Storage Model – Arbitrage + Regulation

- Modeling regulation – need to assume fraction that is assigned



Note: some ISO's provide regulation signal data (e.g., PJM) – can calculate exactly

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU}$$

Account for fraction called

Storage Model – Arbitrage + Regulation + RNS + FCM

- Same model as for arbitrage + regulation
- RNS + FCM +LMP are handled in the cost function
- It is possible to get the benefit of all three using the same "discharge"

Energy Storage Model

P_t^D	price for energy discharged, ($\$/MWh$)
P_t^R	price for energy recharged, ($\$/MWh$)
C_t^D	cost for energy discharged, ($\$/MWh$)
C_t^R	cost for energy recharged, ($\$/MWh$)
P_t^{REG}	price for regulation capacity, ($\$/MWh$)
q_t^D	quantity discharged at time t, (MWh)
q_t^R	quantity recharged at time t, (MWh)
q_t^{REG}	accepted regulation quantity at time t, (MWh)
e^{-rt}	continuous discounting factor at time t

- Arbitrage cost function

$$\max \sum_{t=1}^{T} [(P_t^D - C_t^D)q_t^D - (P_t^R + C_t^R)q_t^R]e^{-rt}$$

$$P_t^D,\ P_t^R = LMP_t$$

- Arbitrage + frequency regulation cost function*

$$\max \sum_{t=1}^{T} [(P_t^D - C_t^D)q_t^D - (P_t^R + C_t^R)q_t^R + q_t^{REG} P_t^{REG}]e^{-rt}$$

$$P_t^D,\ P_t^R = LMP_t$$

C_t^D and C_t^R are assumed to be 0 for this analysis

- Arbitrage + frequency regulation* + RNS + FCM cost function

$$\max \sum_{t=1}^{T} [(P_t^D - C_t^D)q_t^D - (P_t^R + C_t^R)q_t^R + q_t^{REG} P_t^{REG}]e^{-rt}$$

$$P_t^D,\ P_t^R = (LMP_t + FCM_t + RNS_t)$$

*NOTE: ISO-NE implemented a separate pay-for-for-performance mileage bid as of March 31, 2015. Since this analysis spans 2012-2016, we only included the capacity component for consistency.

Historical Data

- Pull data from ISO-NE website using a MATLAB script and the restful services API:

  https://webservices.iso-ne.com/docs/v1.1/

- Advantages:
  - get the data that you need and
  - save in a format that works for you

Optimization Software

- Results were generated with Pyomo – a high level optimization framework developed by Sandia

  http://www.pyomo.org/

- Results were obtained with an open-source solver, GNU Linear Programming Kit (GLPK)
- Other options
  - MATLAB
  - Julia
  - Excel (need a 3rd party library)
  - Other high level optimization languages
  - Production cost modelling tool

Arbitrage Results

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)

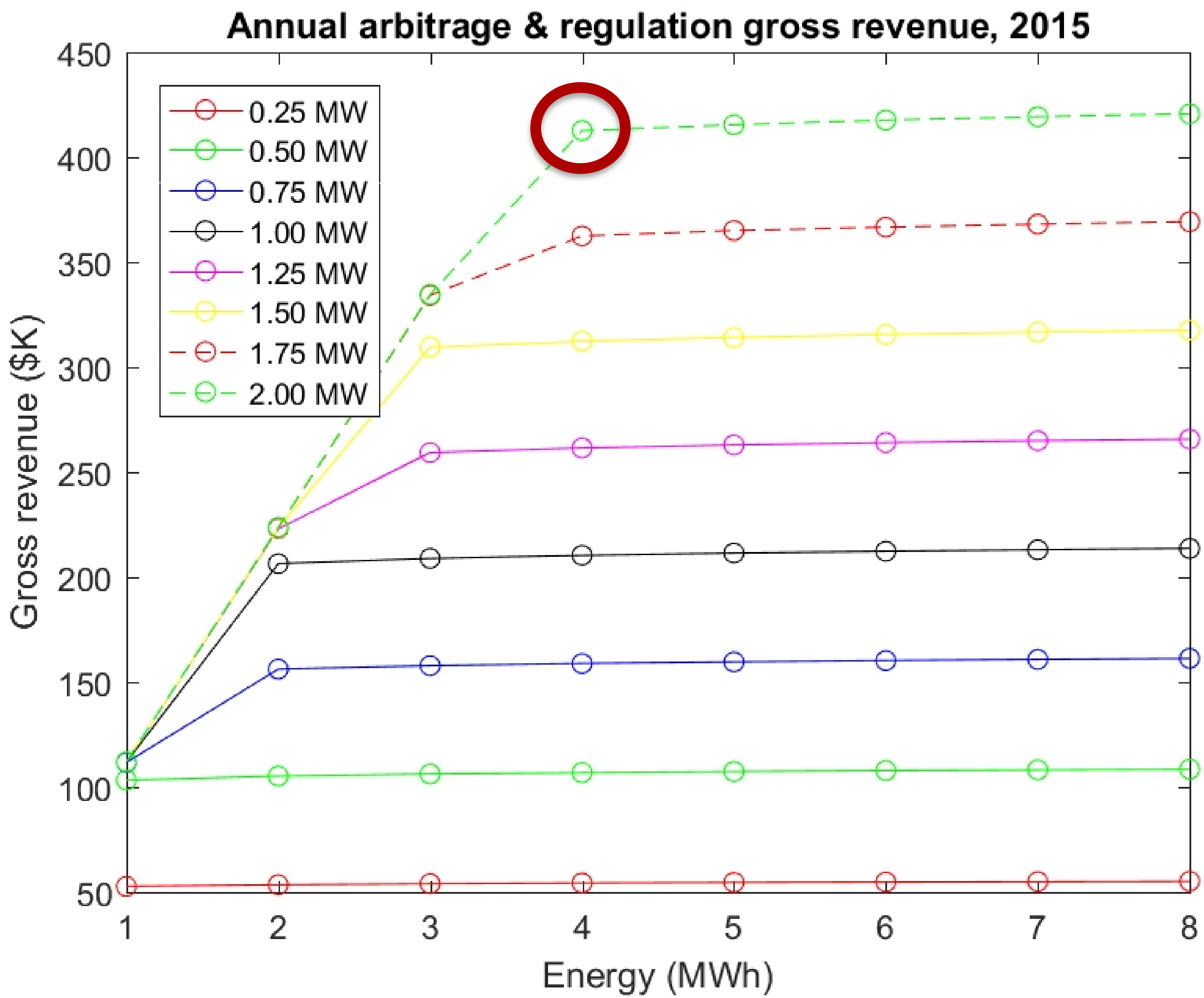
Arbitrage + Regulation Results

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 Results



Arbitrage + Regulation + RNS + FCM

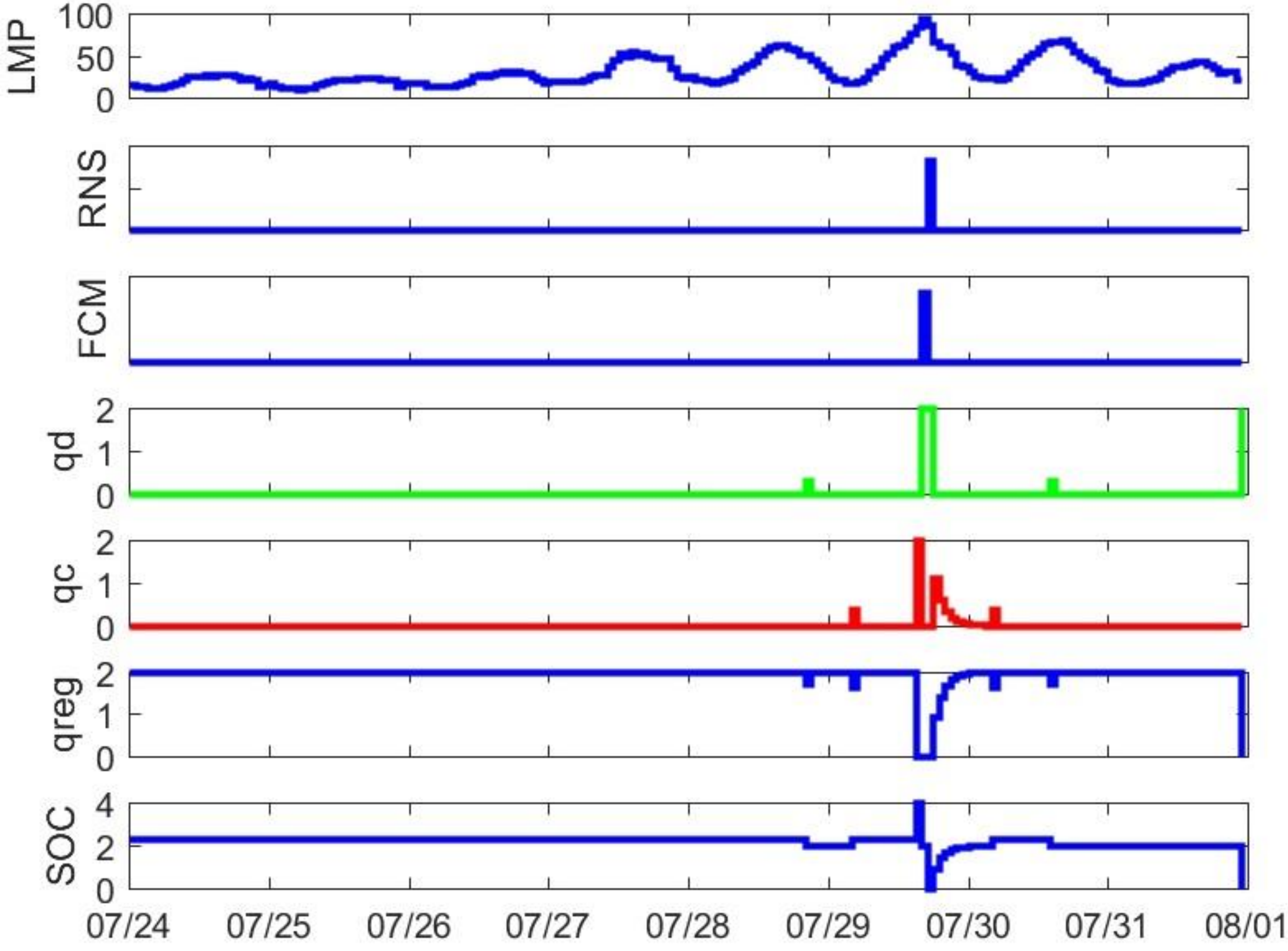
Sandia National Laboratories

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)

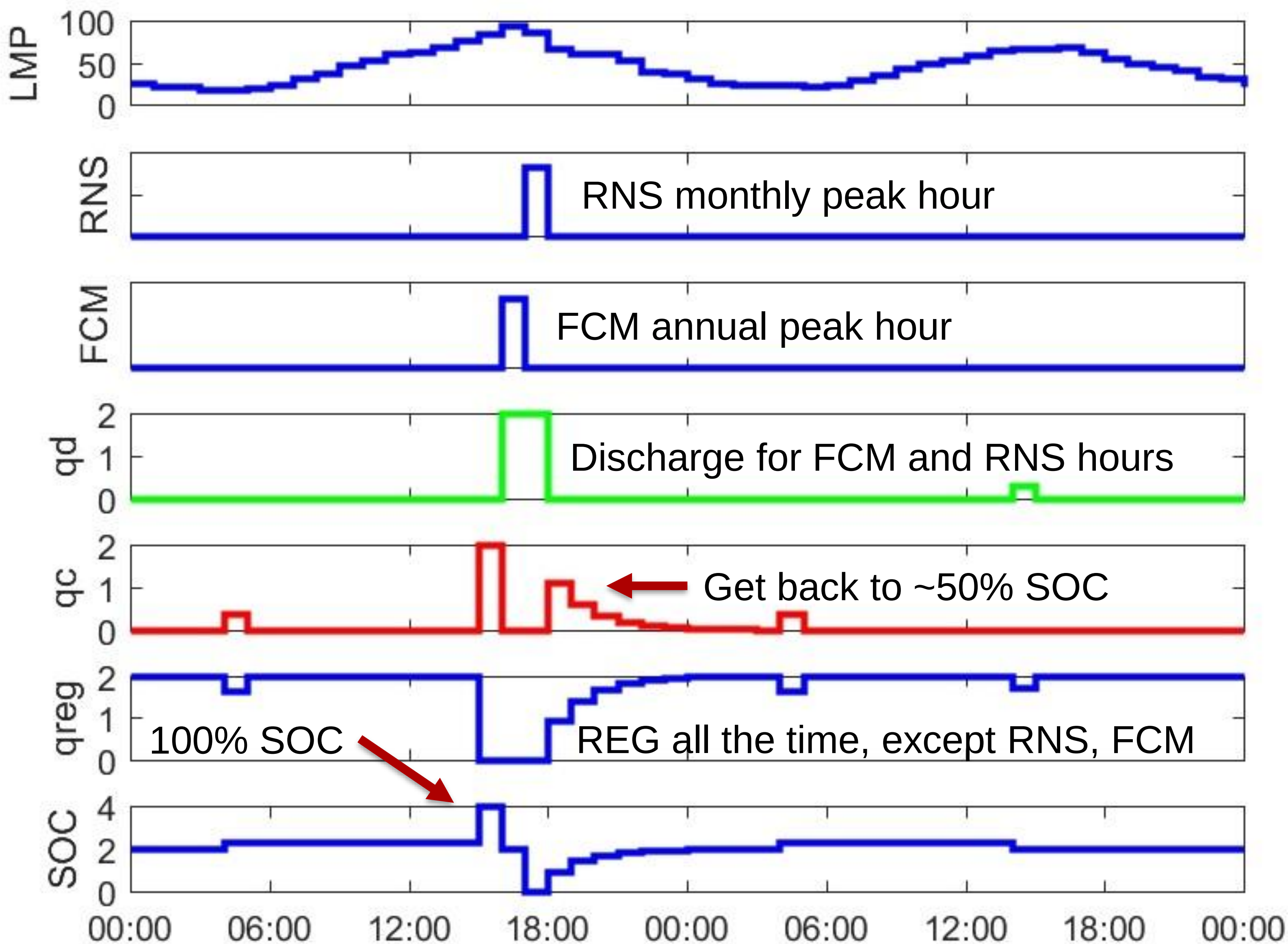
Optimization Results – Typical Week



2 MW, 4 MWh system

- 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

Optimization Results – Typical Day



Grid Resilience

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

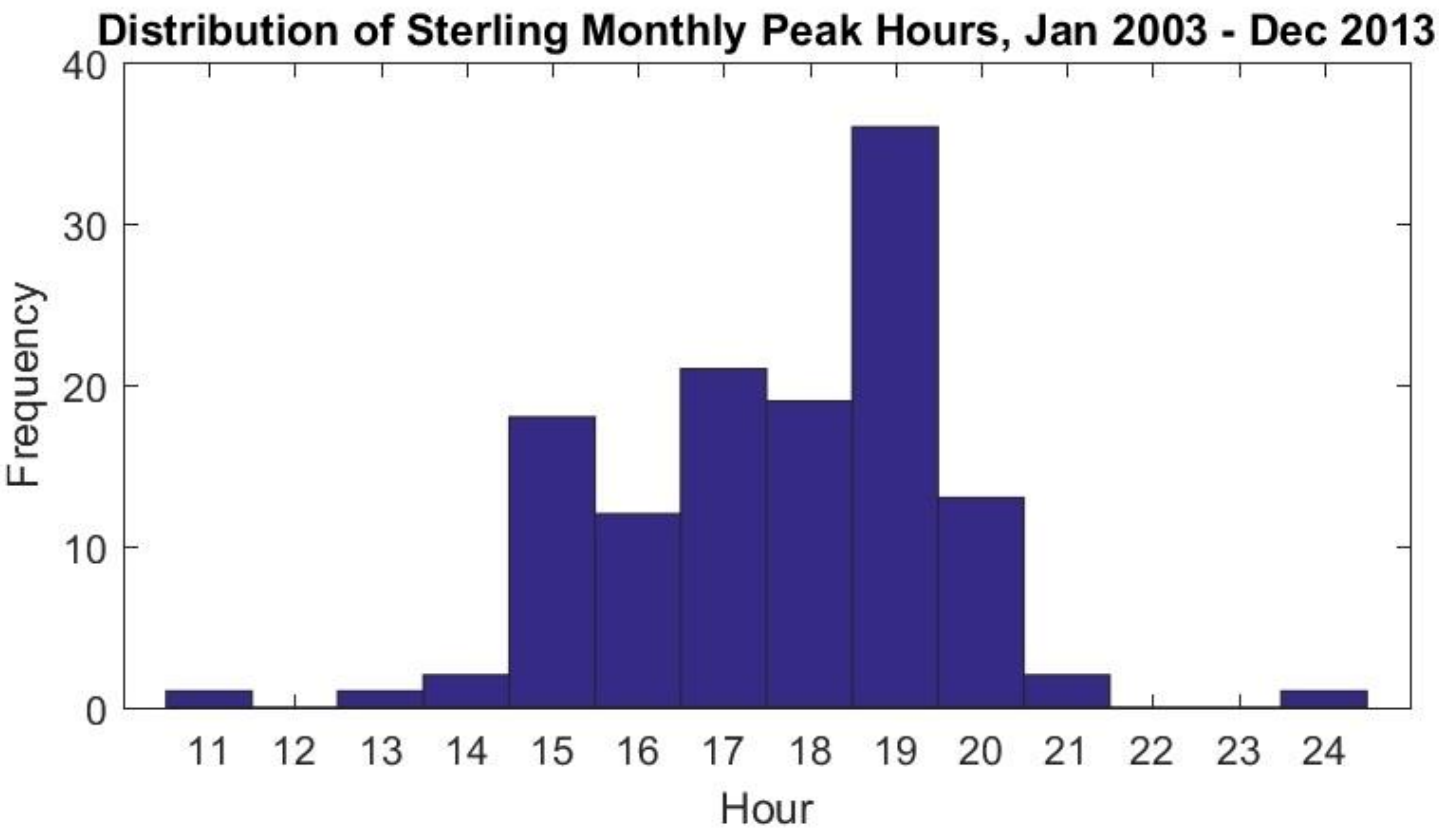
	Capacity			
	1 MWh	2 MWh	3 MWh	4 MWh
Days	4.167	8.333	12.5	16.667
VoLL	$40,819	$81,629	$122,448	$163,267

- 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.

Impact of Capacity

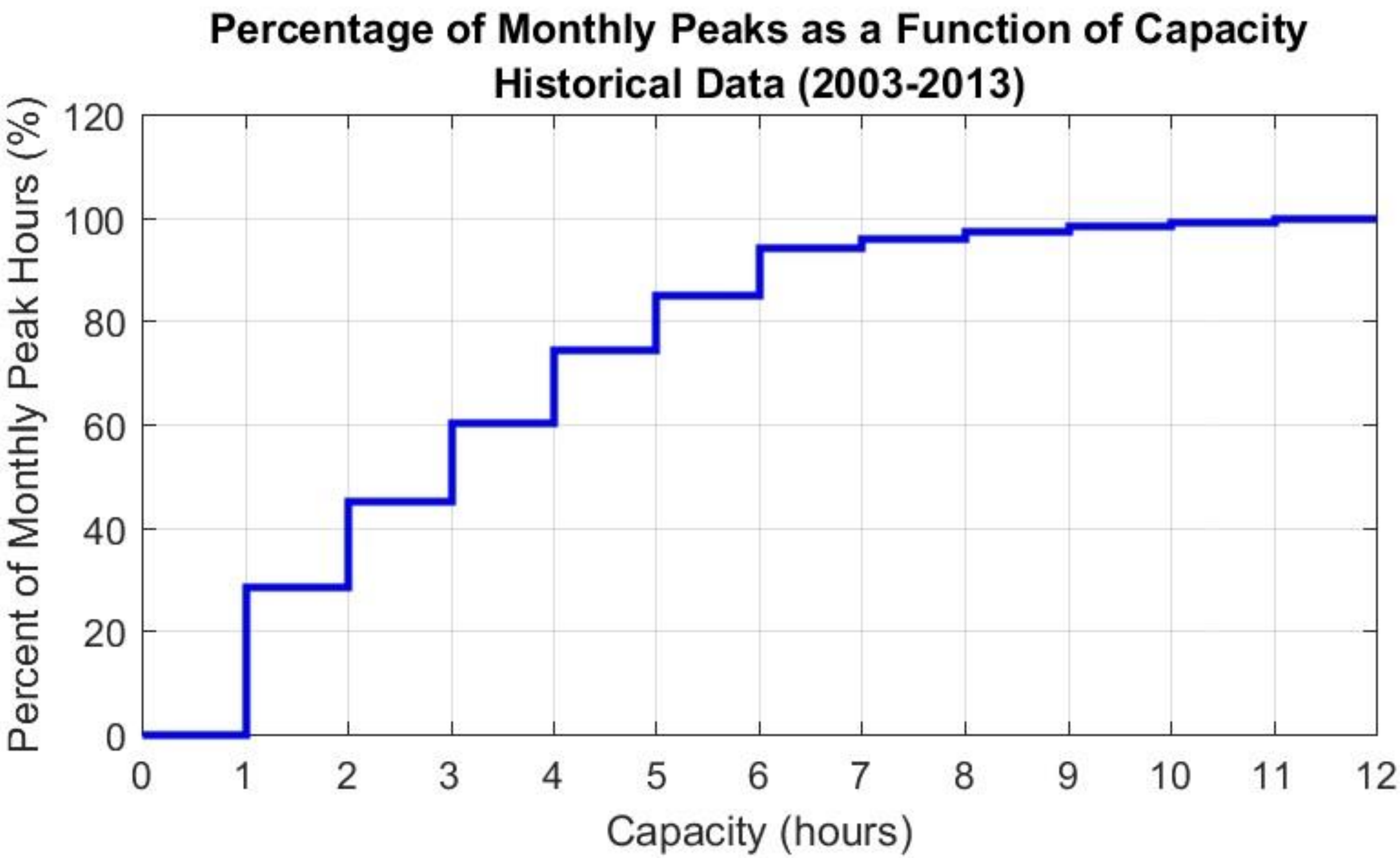
- Increased energy storage capacity increases the likelihood of hitting monthly/annual peaks



Hour	Percent Occurrence
11	0.79 %
12	0.00 %
13	0.79 %
14	1.59 %
15	14.29 %
16	9.52 %
17	16.67 %
18	15.08 %
19	28.57 %
20	10.32 %
21	1.59 %
24	0.79 %

Impact of Capacity

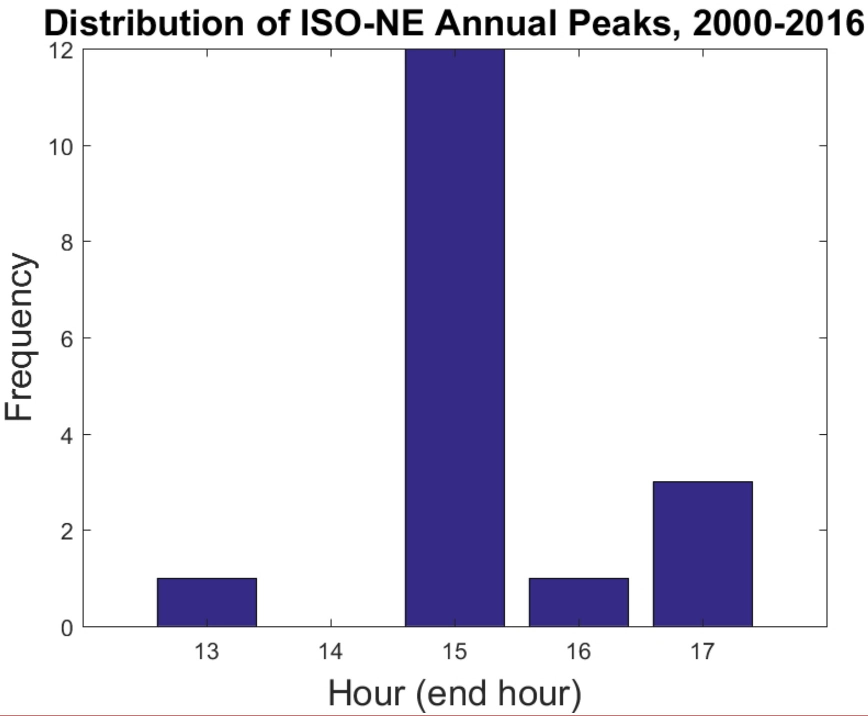
- Impact of capacity on hitting monthly peaks (based solely on historical data)

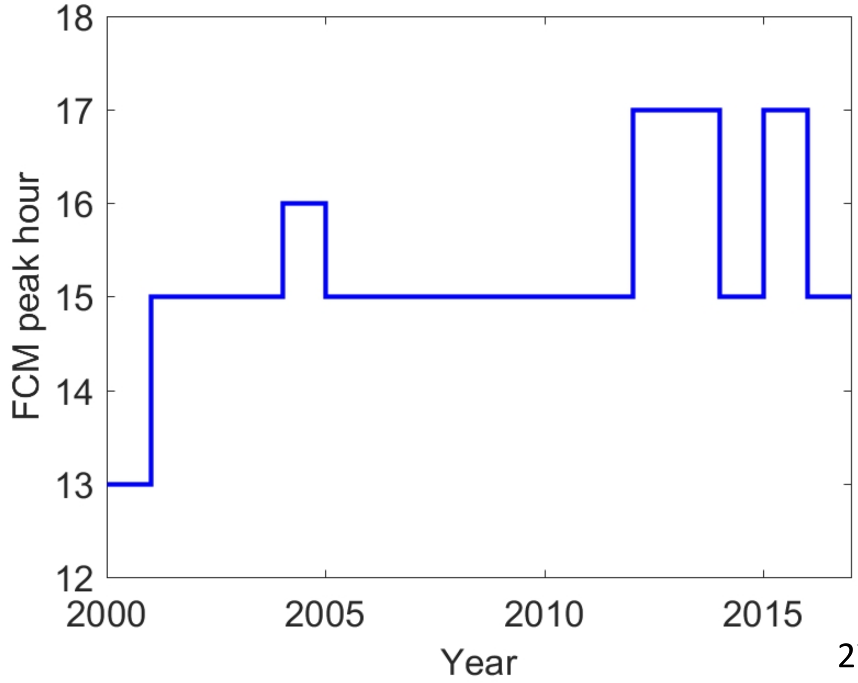


Impact of Capacity

- Distribution of annual peaks, 2000-2016

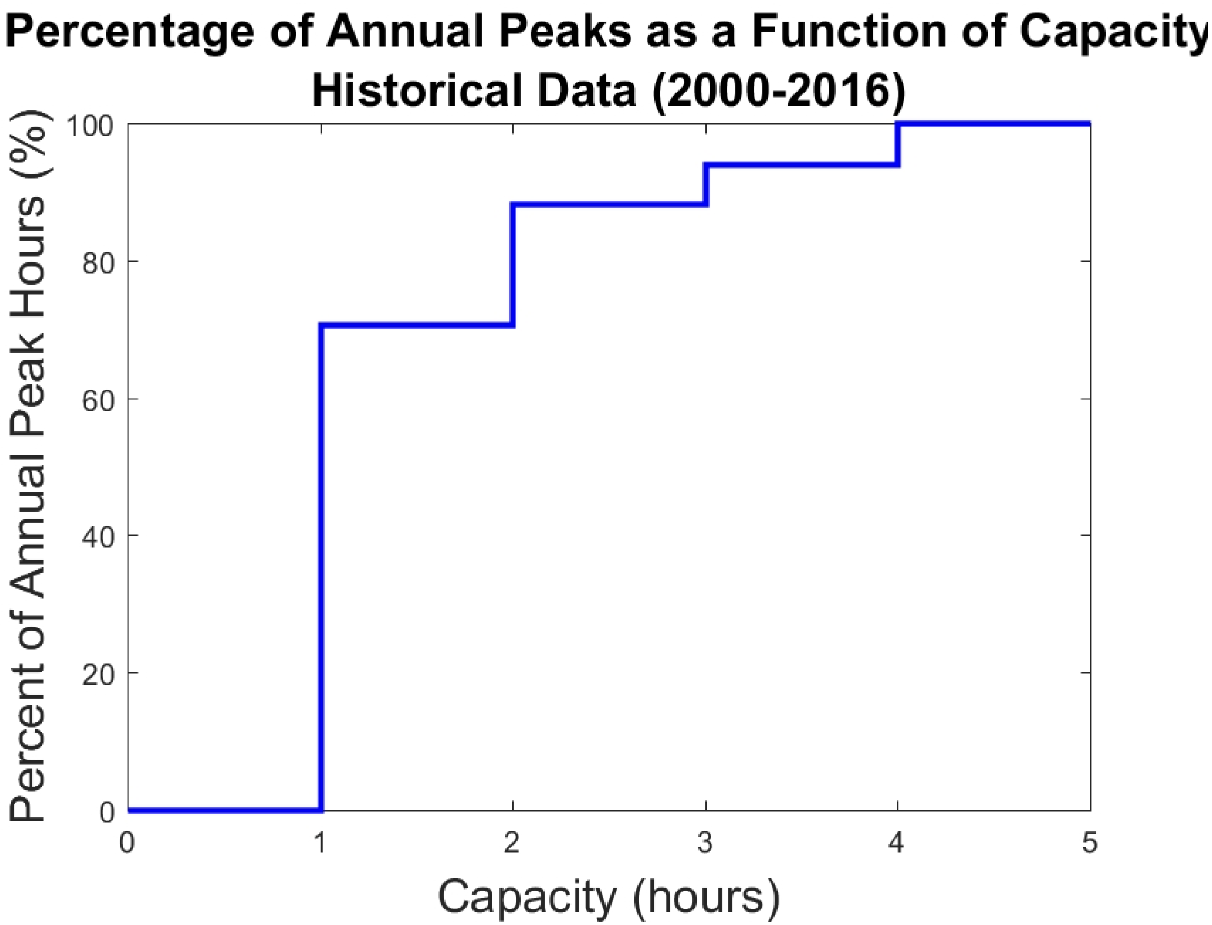
Hour	Percent
13	5.88 %
14	0 %
15	70.59 %
16	5.88 %
17	17.65 %





Impact of Capacity

- Impact of capacity on hitting annual peaks (based solely on historical data)



Future Work

- Investigating algorithms for predicting the monthly and annual peaks
- Plan to release Pyomo example code on the DOE energy storage website (www.sandia.gov/ess) towards the end of 2017

Summary

- Arbitrage is more synergistic with other peak shaving applications
- Total potential revenue, 1MW, 1MWh system

Description	Total	Percent
Arbitrage	$40,738	16.0%
RNS payment	$98,707	38.7%
FCM obligation*	$115,572	45.3%
Total	$255,017	100%

- For a capital cost of ~1.7M, the simple payback is 6.67 years

*2017-2018 data. Rates will likely be higher in the future, resulting in additional savings.

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