Field Operation of Multiple BESSs for Demand Management of a Large-scale Customer

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May 18, 2017

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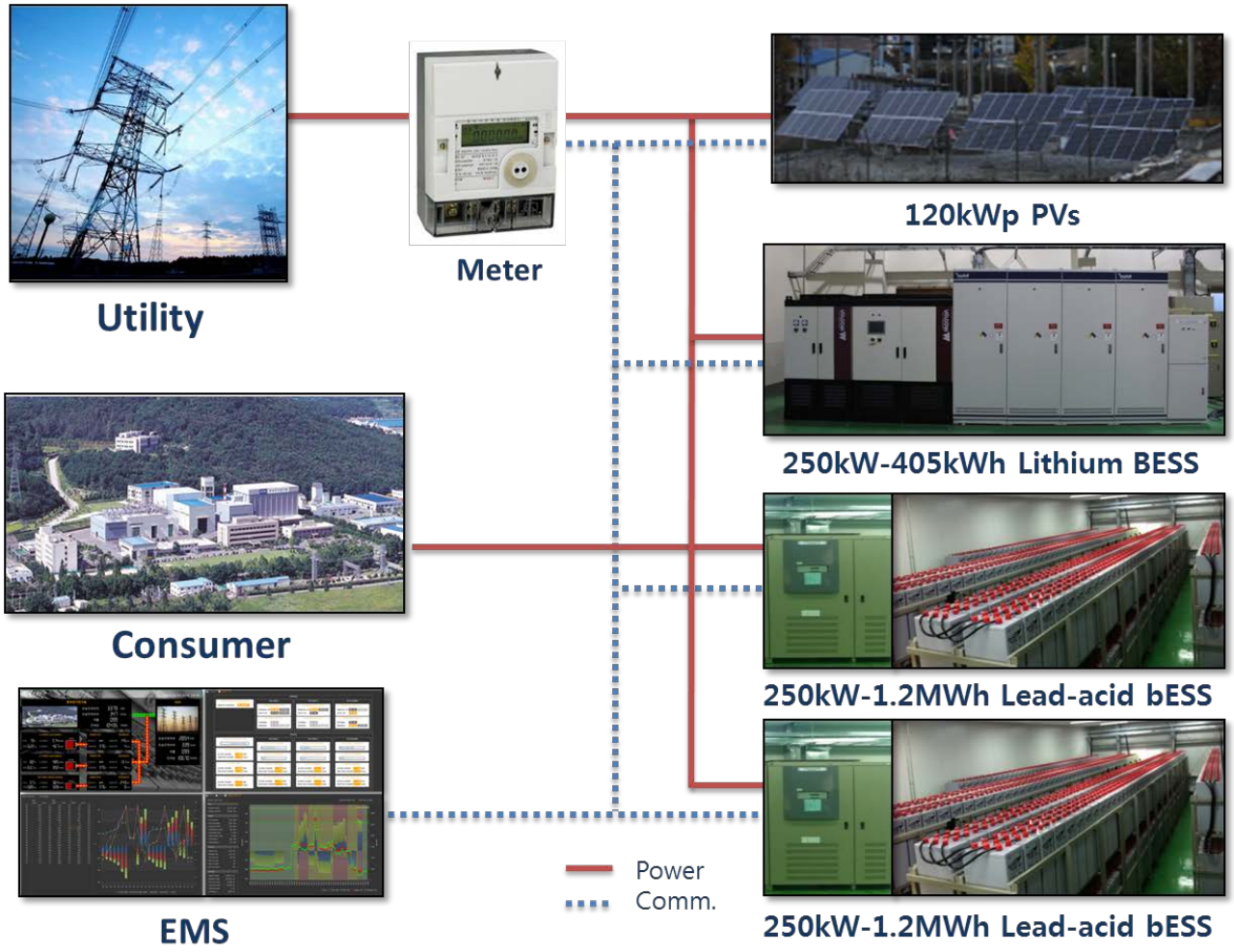
Overview

1. Multiple BESSs in KERI
2. Optimal Operation Framework
3. Field Operation Results
4. Observations

Multiple BESSs in KERI

◆ KERI MG



Multiple BESSs in KERI

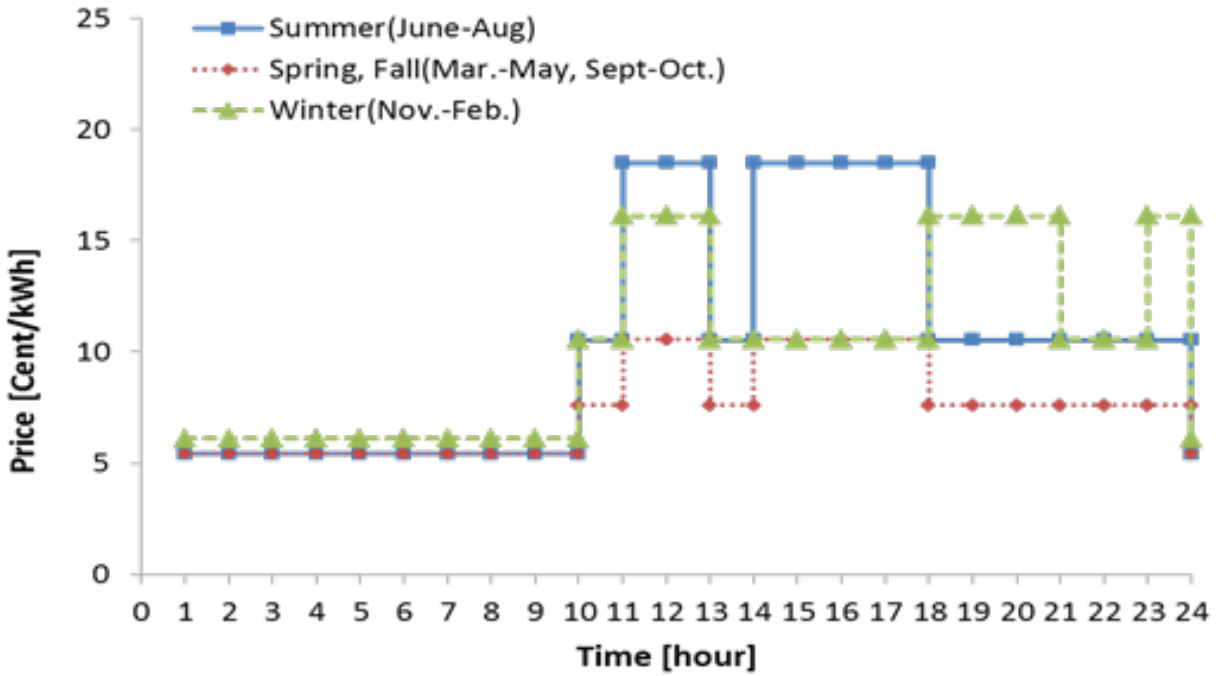
◆ Specifications

	specification	
System	Lead-acid Battery ESS 1 & 2	Lithium Polymer Battery ESS
Battery	• Maintenance-free gel type lead-acid battery • capacity: 1,200kWh * 2 • Life cycle: 2,500 cycles at DOD 70% • BMS (1 Banks, 60 Slaves)	• Lithium polymer battery • Capacity: 405kWh 101.5.kWh * 4 racks • Life cycles: 3,500 cycles at DOD 80% • BMS (1 Bank, 4 Masters, 48 Slaves)
PCS	250kW *2 Units	250kW*1 Unit
EMS	Server 1 (Applications, SCADA), Server 2 (Database)	

Operation Framework

◆ Time-of-Use (TOU) Pricing

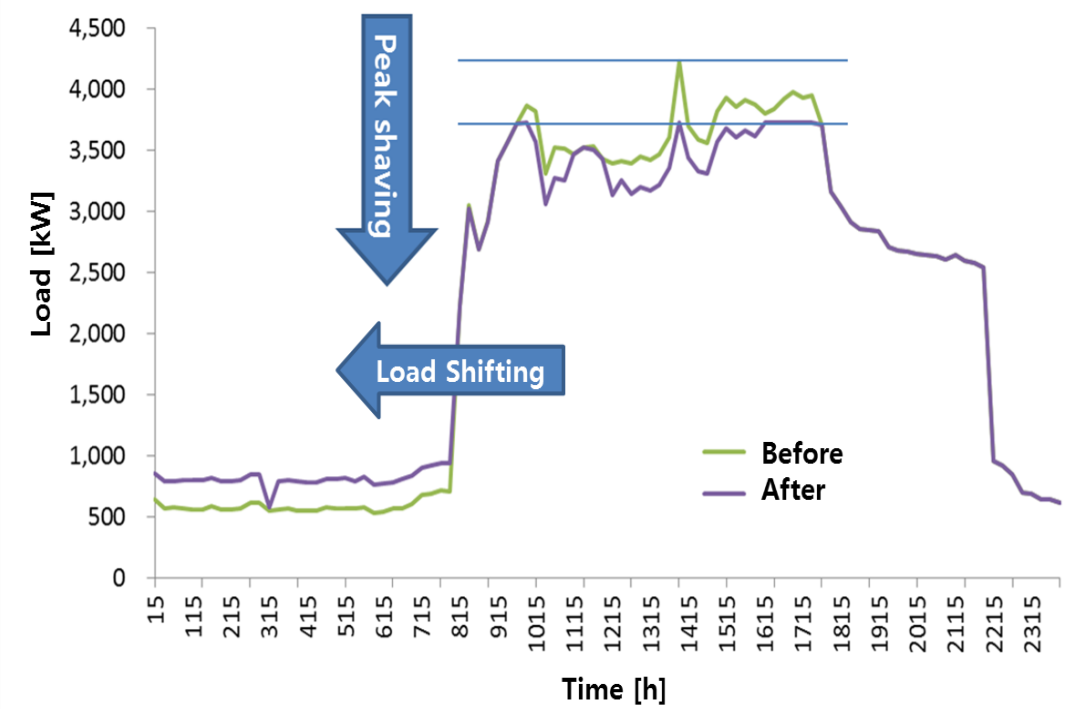
- **Peak charge** based on highest 15 min. average peak of Jan., Feb., Jul., Aug., Nov., Dec., and Current Month in one recent year
- **Energy Charge** based on electricity consumption at each hour



TOU for Industrial Customer

Operation Framework

◆ Operation Strategy

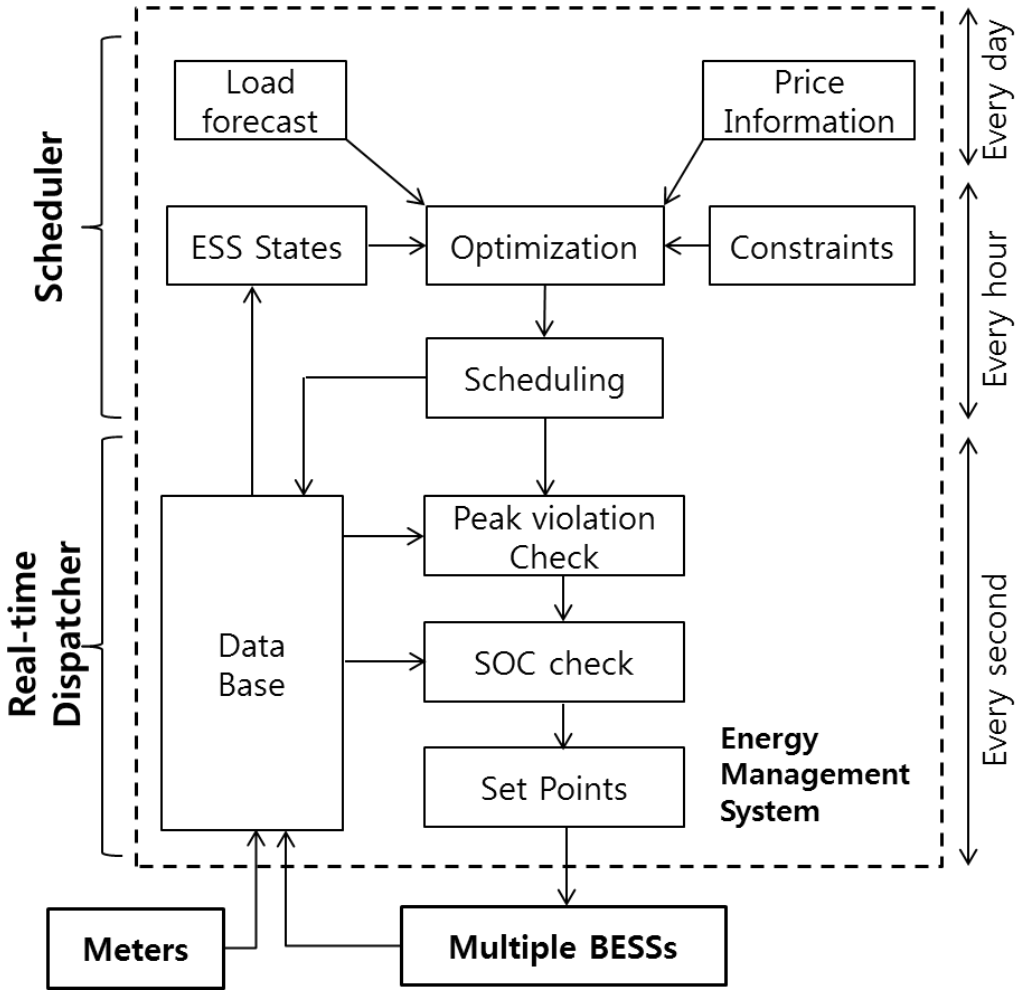


- Peak reduction → Peak charge saving
- Load shifting → Energy charge saving

Operation Framework

◆ Control Process

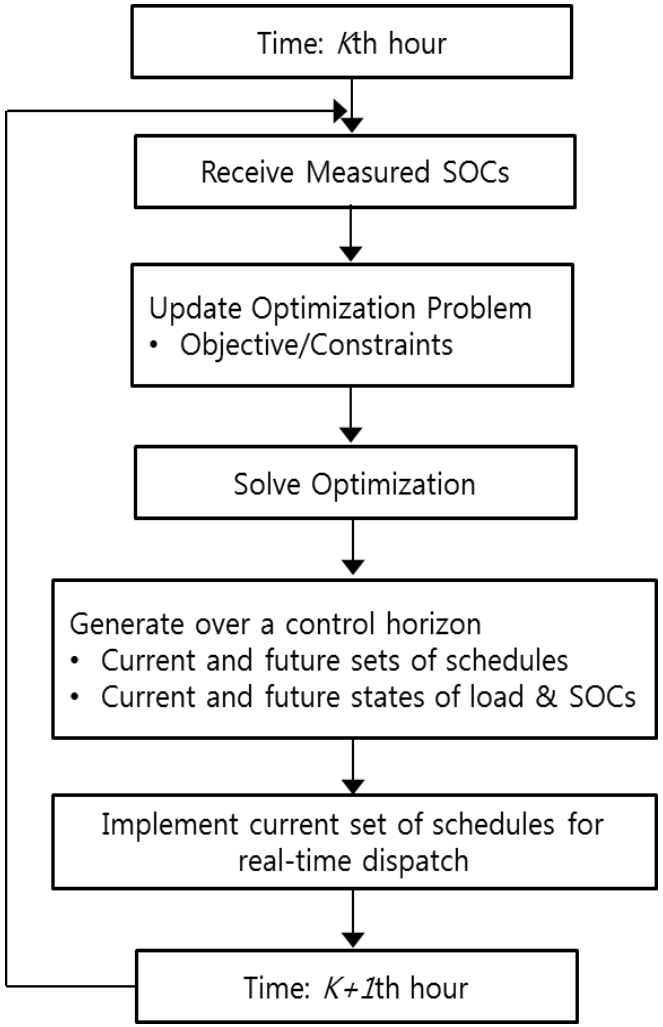
- 2-level control: handling uncertainties in
  - Load forecast
  - SOC estimation
- Scheduler
- Final dispatcher



Operation Framework

◆ Optimal Scheduling

- Cycle: every 1 hour
- Model predictive control
- Objective: daily energy cost minimization
- Constraints
  - Max. and Min. of BESS power
  - Max. and Min. SOCs of Batteries
  - Max. and Min. load
- Modeling Consideration
  - Battery and inverter efficiency (varying)
  - State of Health → active capacity



<MPC>

Operation Framework

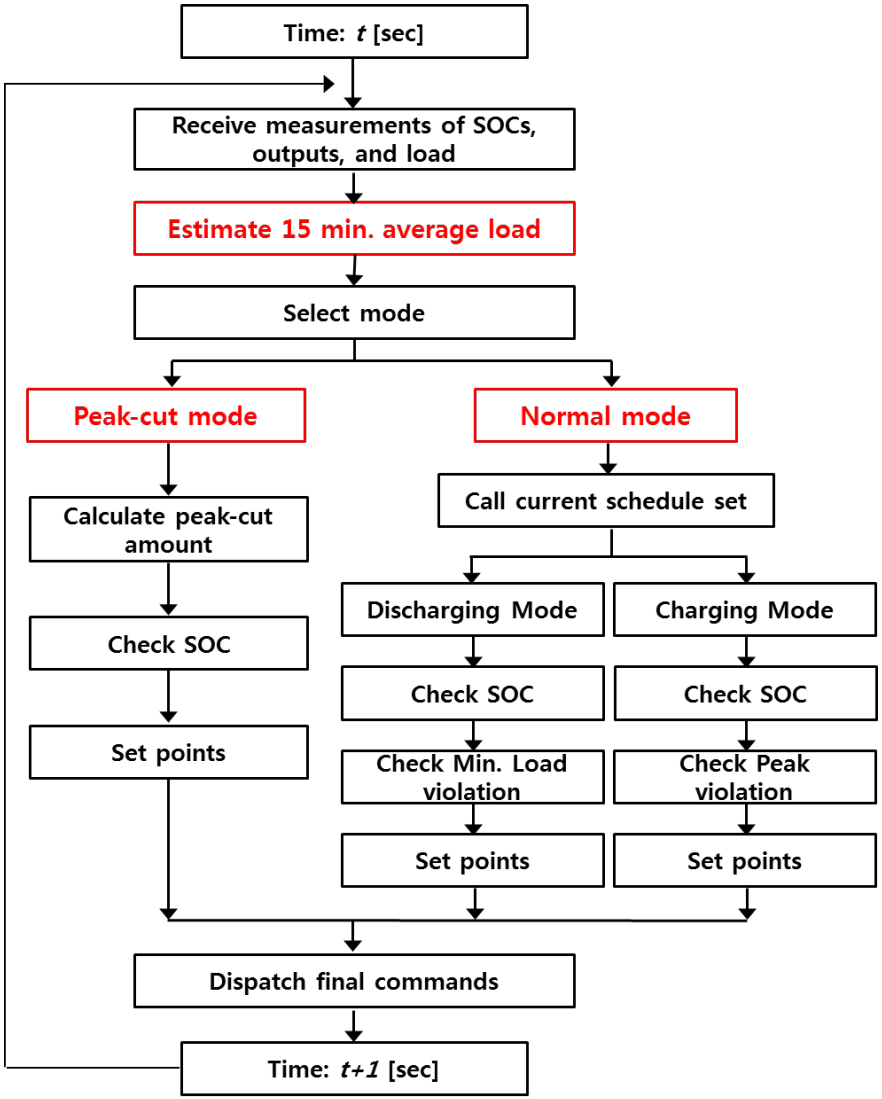
◆ Optimal Scheduling

Time	Input		Lithium BESS			Lead-acid BESS 1			Lead-acid BESS 2				Energy charge	
	Load forecast [kW]	price [cent/kWh]	Schd. [kW]	eff,. [%]	SOC [%]	Schd. [kW]	eff,. [%]	SOC [%]	Schd. [kW]	eff,. [%]	SOC [%]	Mng. load [kW]	Before [USD]	After [USD]
0:00	1,104	6.1	**-51**	95.1	24	**-70**	94.3	55	**-70**	94.3	55	1,296	67	79
1:00	1,087	6.1	**-50**	95.0	36	**-74**	94.3	61	**-74**	94.3	61	1,285	66	78
2:00	1,081	6.1	**-51**	95.1	49	**-74**	94.3	67	**-74**	94.3	67	1,280	66	78
3:00	1,160	6.1	**-53**	95.1	62	**-74**	94.3	73	**-74**	94.3	73	1,361	71	83
4:00	1,116	6.1	**-58**	95.1	76	**-74**	94.3	80	**-74**	94.3	80	1,322	68	81
5:00	1,054	6.1	**0**	91.1	76	**-75**	94.3	86	**-75**	94.3	86	1,204	64	74
6:00	1,161	6.1	**0**	91.1	76	**-79**	94.4	93	**-79**	94.4	93	1,320	71	81
7:00	1,967	6.1	**0**	91.1	76	**-90**	94.5	100	**-90**	94.5	100	2,147	120	131
8:00	3,290	6.1	**-97**	95.5	100	**0**	90.2	100	**0**	90.2	100	3,387	201	207
9:00	3,537	10.6	**0**	91.1	100	**0**	90.2	100	**0**	90.2	100	3,537	374	374
10:00	3,506	16.1	**58**	95.1	84	**155**	91.3	85	**155**	91.3	85	3,138	566	506
11:00	4,397	16.1	**51**	95.1	70	**155**	91.3	70	**155**	91.3	70	4,034	709	651
12:00	4,754	10.6	**-110**	95.5	97	**-60**	94.2	75	**-60**	94.2	75	4,984	502	527
13:00	5,228	10.6	**-1**	91.2	98	**-55**	94.1	79	**-55**	94.1	79	5,339	552	564
14:00	5,584	10.6	**0**	91.1	98	**-62**	94.2	85	**-62**	94.2	85	5,708	590	603
15:00	5,124	10.6	**0**	91.1	98	**-66**	94.2	90	**-66**	94.2	90	5,257	541	556
16:00	4,652	10.6	**-9**	91.8	100	**-117**	94.7	100	**-117**	94.7	100	4,895	492	517
17:00	3,597	16.1	**53**	95.1	86	**208**	86.8	79	**208**	86.8	79	3,129	580	505
18:00	3,267	16.1	**0**	91.1	86	**208**	86.8	58	**208**	86.8	58	2,852	527	460
19:00	2,673	16.1	**57**	95.1	70	**208**	86.8	37	**208**	86.8	37	2,201	431	355
20:00	3,684	10.6	**-55**	95.1	84	**-117**	94.7	46	**-117**	94.7	46	3,973	389	420
21:00	3,384	10.6	**1**	91.2	83	**-119**	94.6	56	**-119**	94.6	56	3,620	358	382
22:00	773	16.1	**250**	95.0	15	**208**	86.8	35	**208**	86.8	35	107	125	17
23:00	1,156	6.1	**0**	91.1	15	**-150**	92.5	47	**-150**	92.5	47	1,456	71	89
Total	-	-	**-**	-	-	-	-	-	-	-	-	-	7,602	7,417

Operation Framework

◆ Real-time Dispatch

- Cycle: 1 second
- Uncertainty in load forecast and SOC estimation
- Prevention of violation of constraints
  - SOC and Load constraints
- Power sharing in peak-cut mode
- Real-time estimation of 15 min. average load



Field Operation Results

◆ ESS Management System (EMS)

▲ Overview
▼ Schedule

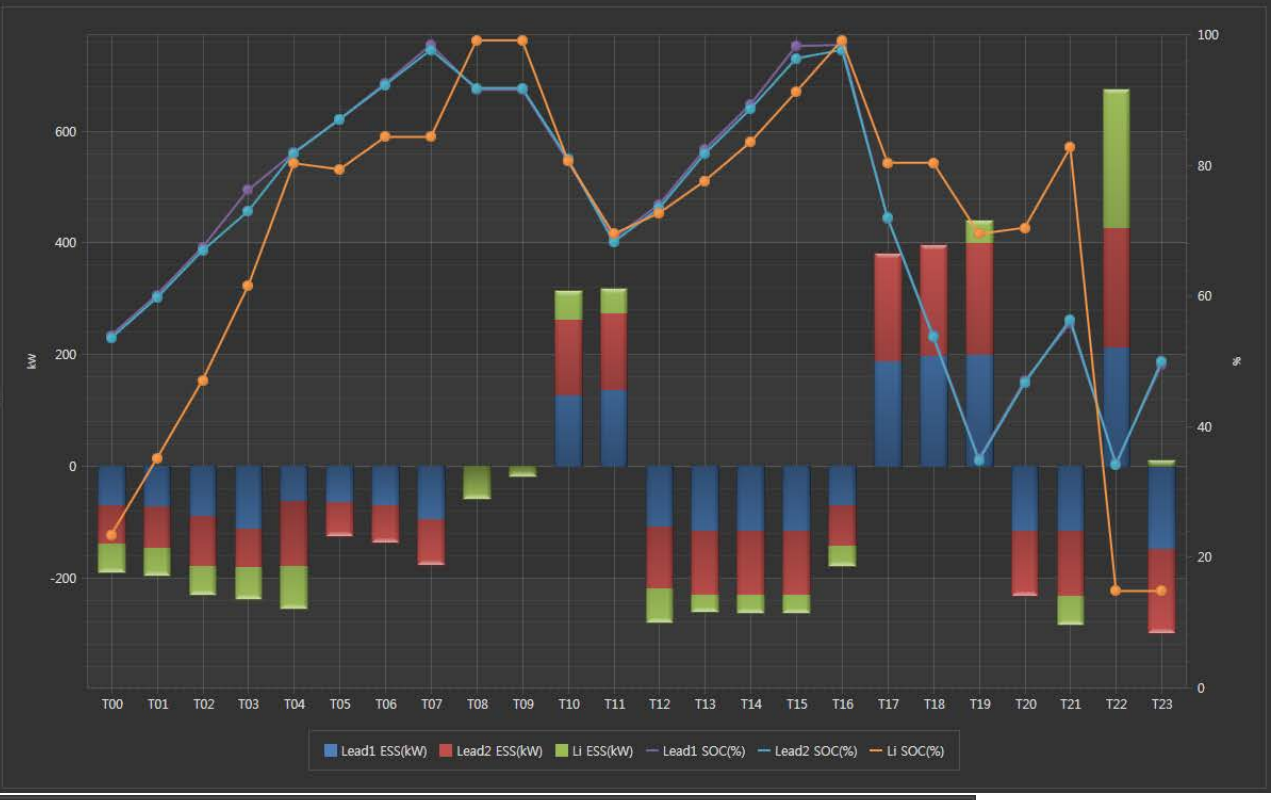
▲ Main Control
▼ Operation result

Field Operation Results

◆ EMS - scheduling

기준 일자 2015-12-11 ESS ID 전체ESS

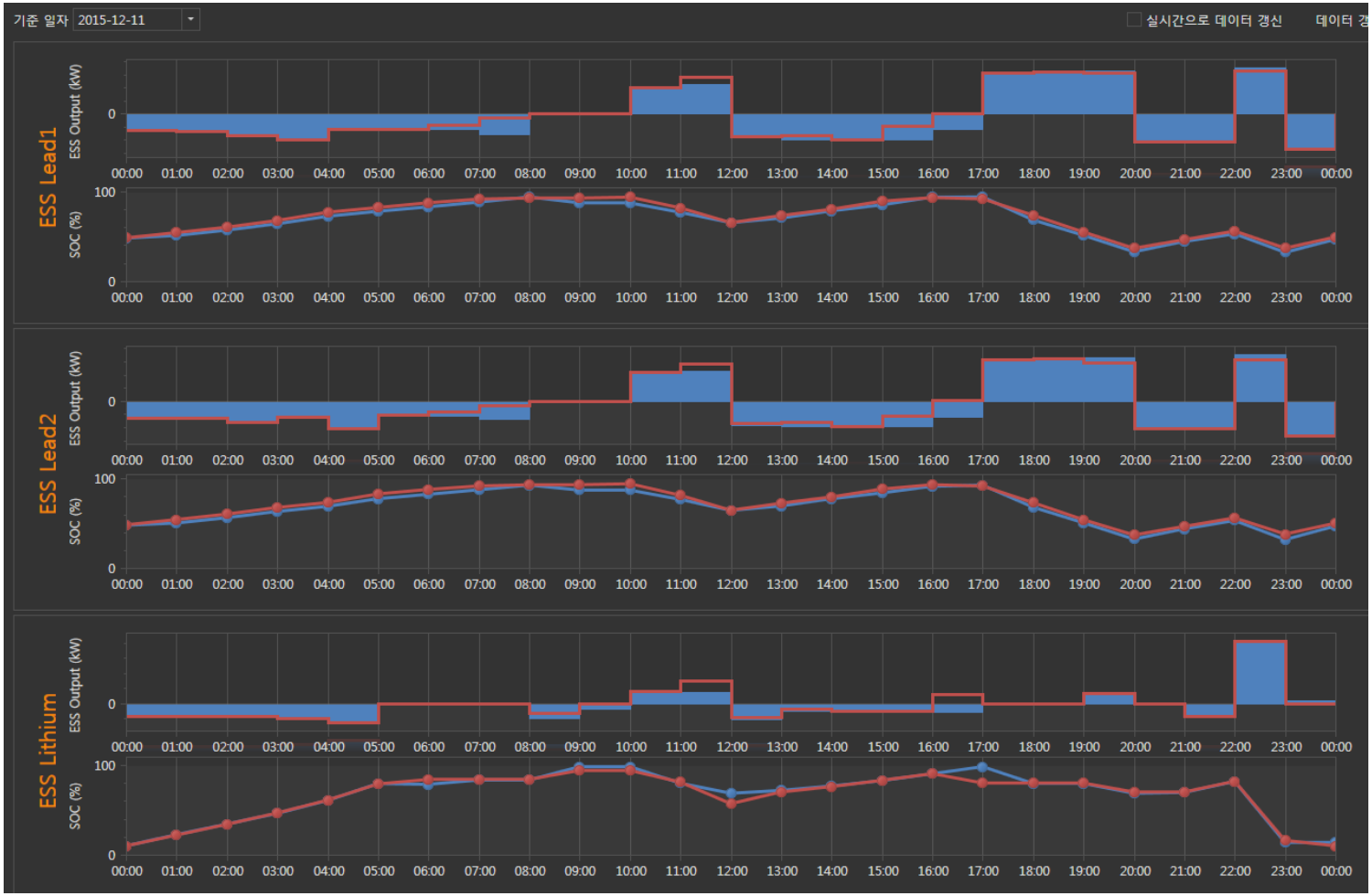
	Lead1		Lead2		Li	
	ESS(kW)	SOC(%)	ESS(kW)	SOC(%)	ESS(kW)	SOC(%)
T00	-70.3	54.1	-70.3	53.6	-51.4	23.5
T01	-73.7	60.3	-73.7	59.8	-50.4	35.2
T02	-90.3	67.6	-90.3	67.0	-50.6	47.2
T03	-112.4	76.3	-68.7	73.1	-58.6	61.6
T04	-62.8	82.0	-116.7	81.9	-76.6	80.4
T05	-64.9	87.1	-61.0	87.1	0.0	79.5
T06	-71.7	92.6	-65.8	92.4	0.0	84.4
T07	-95.2	98.5	-83.4	97.8	0.0	84.4
T08	0.0	91.7	0.0	91.9	-60.3	99.2
T09	0.0	91.7	0.0	91.9	-20.3	99.2
T10	127.3	80.8	136.8	81.1	50.1	80.8
T11	137.4	68.9	137.4	68.3	43.5	69.6
T12	-110.1	74.1	-110.1	73.6	-61.8	72.8
T13	-116.1	82.5	-116.1	81.9	-29.8	77.7
T14	-116.1	89.4	-116.1	88.7	-32.3	83.7
T15	-117.1	98.4	-114.9	96.4	-32.7	91.3
T16	-71.5	98.5	-71.5	97.8	-36.5	99.2
T17	189.7	72.0	192.5	72.0	0.0	80.5
T18	198.0	54.2	198.0	53.8	0.0	80.5
T19	200.5	35.2	200.5	34.9	39.8	69.6
T20	-116.9	47.1	-116.9	46.7	0.0	70.5
T21	-116.9	56.0	-116.9	56.5	-50.1	82.8
T22	214.2	34.5	214.2	34.3	247.3	14.9
T23	-150.0	49.5	-150.0	50.1	11.4	14.9



Lead1 ESS(kW) Lead2 ESS(kW) Li ESS(kW) Lead1 SOC(%) Lead2 SOC(%) Li SOC(%)

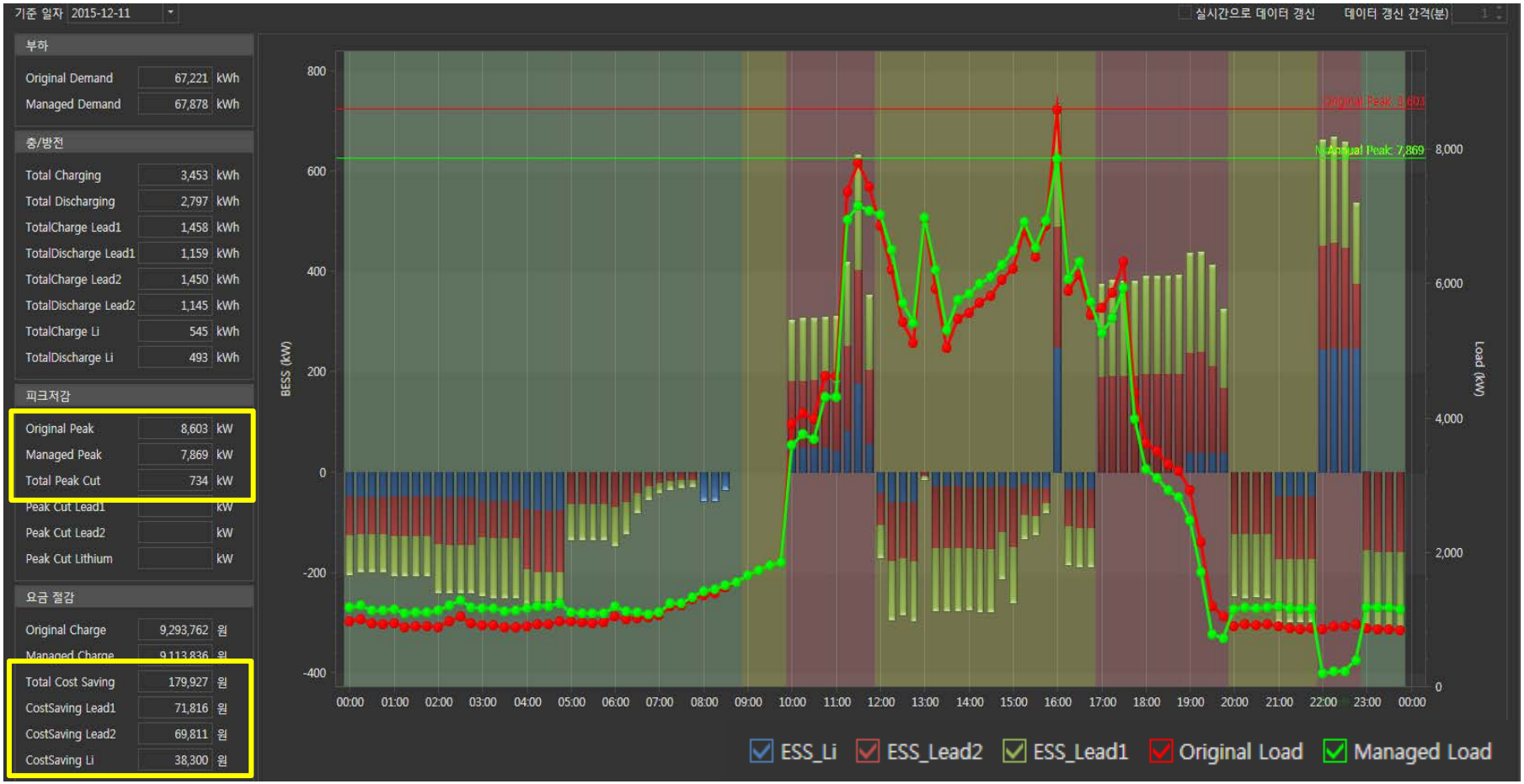
Field Operation Results

◆ EMS - schedule vs actual operation



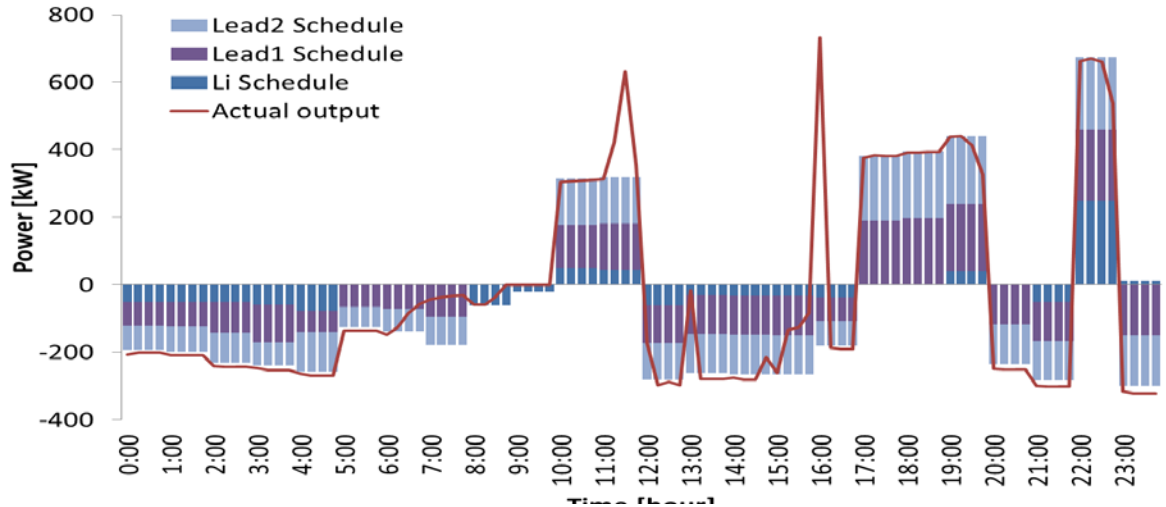
Field Operation Results

◆ EMS - operation result

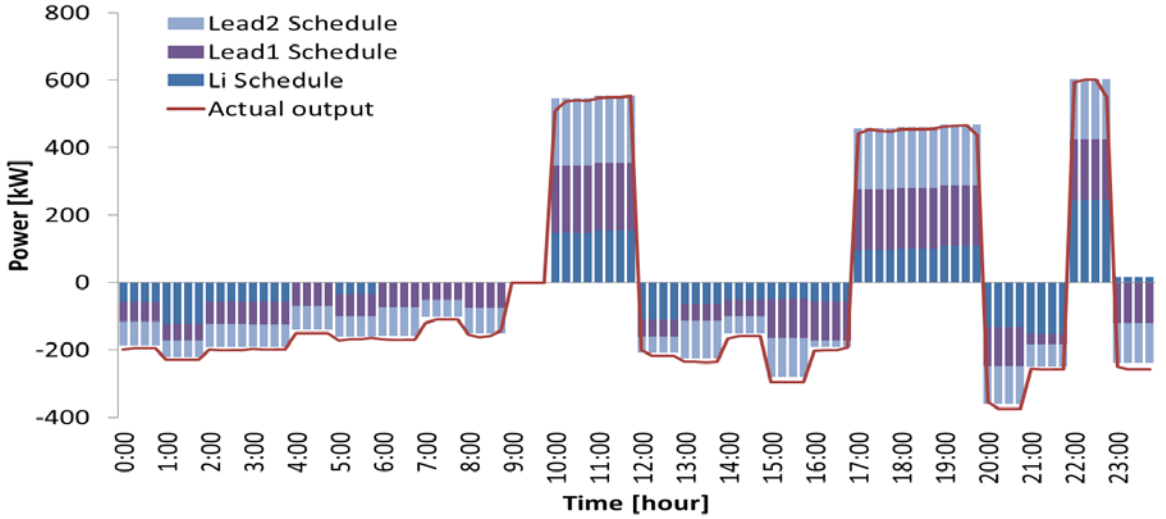


Field Operation Results

◆ Actual Power vs Schedule



Peak day



Off-peak day

Field Operation Results

◆ Performance Indices

- **PMI** (Peak Management Index)

  = Actual peak reduction [kW] / Total sum of BESS inverters [kW]

- **OPI** (Optimal operation Performance Index)

  = Actual energy cost saving [KRW] / Max. available energy cost saving* [KRW]

*Under peak load constraint

Field Operation Results

◆ PMI Performance

Month	Original Peak [kW]	Managed Peak [kW]	Peak Reduction [kW]	PMI [%]
Jul. 2015	5,812	5,207	605	**80.7**
Aug.	6,347	5,710	637	**84.9**
Sep.	6,347	5,710	637	**84.9**
Oct.	6,347	5,710	637	**84.9**
Nov.	6,813	6,278	535	**71.3**
Dec.	8,603	7,869	734	**97.9**
Jan. 2016	8,603	7,869	734	**97.9**
Feb.	8,603	7,869	734	**97.9**
Mar.	8,603	7,869	734	**97.9**
Apr.	8,603	7,869	734	**97.9**
May	8,603	7,869	734	**97.9**
Jun.	8,603	7,869	734	**97.9**
Jul.	8,603	7,869	734	**97.9**
Aug.	8,603	7,869	734	**97.9**
Sep.	8,603	7,869	734	**97.9**
Oct.	8,603	7,869	734	**97.9**
Nov.	8,603	7,869	734	**97.9**
Dec.	8,490	7,891	600	**80.0**

Field Operation Results

◆ OPI

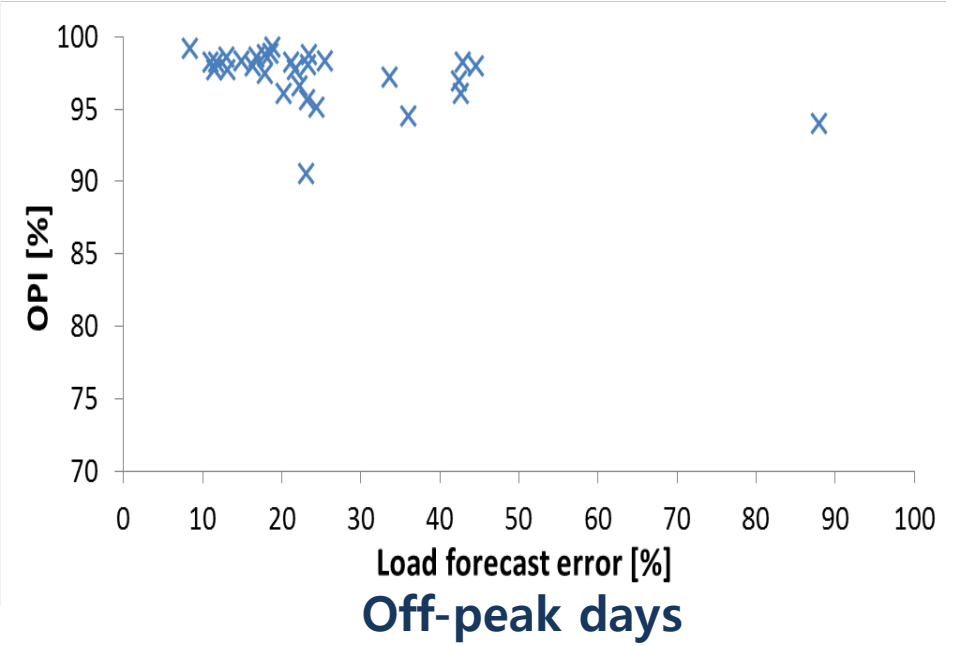
- Off-peak days: 30 working days of Feb., Mar., and Jun. (2016)
- Peak days: 27 days of 2016

Period		LAB 1	LAB 2	LIB	Total
Feb. 2016 (Winter)	MES*	$ 811	$ 766	$ 571	$ 2,148
	AES**	$ 783	$ 732	$ 553	$ 2,068
	OPI	**96.6%**	**95.6%**	**96.8%**	**96.3%**
Mar. 2016 (Spring/Fall)	MES	$ 350	$ 312	$ 179	$ 841
	AES	$ 341	$ 307	$ 170	$ 818
	OPI	**97.6%**	**98.4%**	**94.7%**	**97.3%**
Jun. 2016 (Summer)	MES	$ 998	$ 882	$ 497	$ 2,337
	AES	$ 996	$ 874	$ 470	$ 2,340
	OPI	**99.8%**	**99.1%**	**94.5%**	**98.4%**
Peak days	MES	$2,085	$1,693	$876	$4,655
	AES	$1,909	$1,479	$753	$4,141
	OPI	**91.5%**	**87.4%**	**86.0%**	**89.0%**

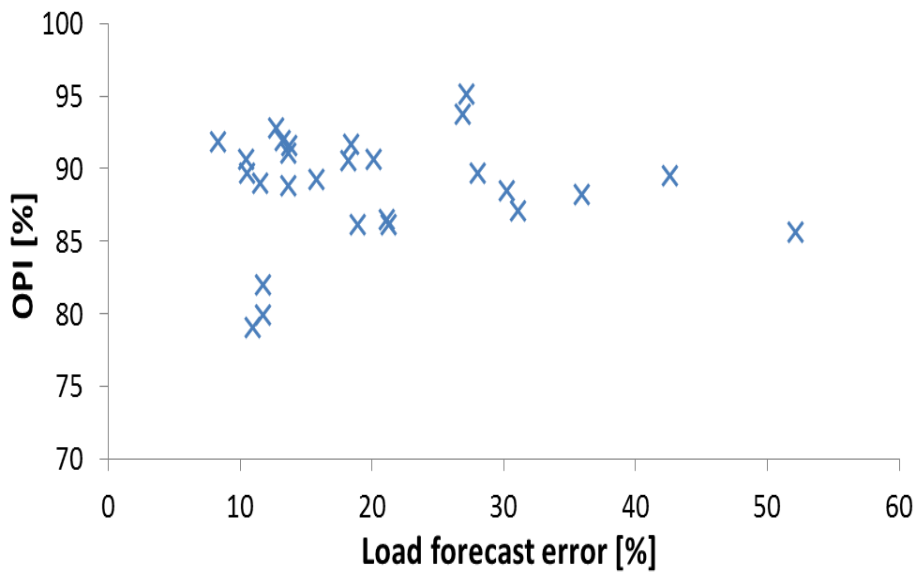
*MES: maximum energy charge saving with peak management
**AES: actual energy charge saving

Field Operation Results

◆ OPI vs Load forecast error



Off-peak days



Peak days

Overall, robust to load forecast uncertainty

Field Operation Results

◆ Cost Saving in 2015

Month	Peak reduction [kW]			Peak charge saving [USD]	Energy charge saving [USD]			Total Saving [USD]
	before	after	peak-cut		LIB	LAB 1	LAB 2	
1	4,200	3,894	306	**2,465**	574	1,108	1,061	**5,209**
2	4,295	3,980	315	**2,551**	424	997	905	**4,858**
3	4,295	3,980	315	**2,551**	94	507	457	**3,591**
4	4,295	3,980	315	**2,551**	319	658	591	**4,101**
5	4,295	3,980	315	**2,551**	303	553	423	**3,813**
6	4,295	3,980	315	**2,551**	854	1,852	693	**5,932**
7	5,812	5,207	605	**4,870**	684	1,877	1,135	**8,566**
8	6,347	5,710	637	**5,126**	826	2,084	1,850	**9,886**
9	6,347	5,710	637	**5,126**	454	562	487	**6,629**
10	6,347	5,710	637	**5,126**	294	550	197	**6,167**
11	6,813	6,278	535	**4,308**	872	1,574	420	**7,174**
12	8,603	7,869	734	**5,909**	746	1,314	1,307	**9,277**
Total				**45,596**	6,444	13,636	9,525	**75,203**

Field Operation Results

◆ Cost Saving in 2016

Newly enforced!

Month	Peak reduction [kW]			Peak charge saving [USD]	Energy charge saving [USD]			ESS Incentive [USD]		Total Saving [USD]
	before	after	peak-cut		LIB	LAB 1	LAB 2	charging discount	peak discount	
1	8,603	7,869	734	**5,910**	723	1,420	1,366	-	-	**9,419**
2	8,603	7,869	734	**5,910**	948	1,264	1,206	-	-	**9,328**
3	8,603	7,869	734	**5,910**	383	703	621	-	-	**7,617**
4	8,603	7,869	734	**5,910**	363	652	575	-	-	**7,500**
5	8,603	7,869	734	**5,910**	347	603	531	-	-	**7,391**
6	8,603	7,869	734	**5,910**	775	2,038	1,791	-	-	**10,514**
7	8,603	7,869	734	**5,910**	944	1,943	1,034	219	4,206	**14,255**
8	8,603	7,869	734	**5,910**	716	2,143	814	182	3,643	**13,407**
9	8,603	7,869	734	**5,910**	238	578	417	240	4,346	**11,729**
10	8,603	7,869	734	**5,910**	30	568	409	223	3,559	**10,698**
11	8,603	7,869	734	**5,910**	523	1,492	1,243	269	6,764	**16,200**
12	8,491	7,891	600	**4,829**	805	1,509	1,370	310	7,383	**16,205**
Total				**69,837**	6,795	14,913	11,376	1,443	29,901	**134,262**

Field Operation Results

◆ Cost Saving in 2017

Month	Peak reduction [kW]			Peak charge saving [USD]	Energy charge saving [USD]			ESS Incentive [USD]		Total Saving [USD]
	before	after	peak-cut		LIB	LAB 1	LAB 2	charging discount	peak discount	
1	9,023	8,306	717	**5,774**	741	1,533	1,407	1,620	27,100	**38,174**
2	9,152	9,030	122	**981**	717	1,527	1,337	1,710	27,100	**33,372**
3	9,152	9,030	122	**981**	286	683	515	1,692	18,177	**22,334**
Total				**7,736**	1,744	3,743	3,259	5,022	72,377	**93,880**

- Big leap in cost saving from 2017 by the promotion incentive
- Sudden drop in peak reduction due to communication failure

Field Operation Results

◆ Operation Characteristics (2014~2016)

Year	Lithium BESS				Lead-acid BESS 1				Lead-acid BESS 2			
	Char. [kWh]	Dischar. [kWh]	Eff. [%]	Cycle	Char. [kWh]	Dischar. [kWh]	Eff. [%]	Cycle	Char. [kWh]	Dischar. [kWh]	Eff. [%]	Cycle
2014	138,845	125,449	90.6	408	122,612	97,063	79.9	153	122,521	99,359	81.7	130
2015	148,209	133,296	89.8	435	335,197	268,910	80.3	314	258,100	205,261	79.5	242
2016	144,528	130,267	90.1	424	349,615	280,125	80.1	328	284,126	228,420	80.4	266
Total	431,582	389,012	**90.1**	1,267	807,424	646,098	**80.0**	795	664,747	533,040	**80.2**	638
Monthly Average	11,988	10,806	-	35.2	26,914	21,537	-	26.5	22,158	17,768	-	21.3

Observations

◆ Operation Performance

- Cost saving target ($100K per year) reached in the 3rd year after 2 years of stabilization (in 2014 and 2015)
- 96 to 98% of ideal saving reached on off-peak days, 89% on peak-days, and 71 to 98% of ideal peak-cut in normal operation
- Two-level control scheme effective to handle uncertainty
- Overall reliability such as communication, electronic parts, etc. is crucial as well as control performance

Observations

◆ Economic Evaluation

- Based on cost saving effect over the recent 1 year
- 15 year-operation scenario under promotion policy in place
- NPV(discount rate 5%), Bat. degradation, & Price change incl.

	With Incentive	Without Incentive
CAPEX	$1,070K	
OPEX	$160K	
Profit	$1,189K	-$167K
ROI	211%	84%
Payback	3.1 year	> 15 year

Observations

◆ Future Work

- State-of-health (SOH) Analysis
- Incorporation of Redox Flow Battery systems
- Upgrades on Optimal Operation Process

Thank You !