The Wide-Area Energy Storage and Management (WAESM) System

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General Goals & Objectives

- Develop principles, algorithms, functional design and technical specification for the WAESM system.
- Create additional cost-effective and efficient regulation resources to cope with the wind generation intermittency.
- Provide more fast responsive regulation resources available for AGC control.
- Minimize the required regulation capacity by sharing regulation services between balancing authorities.
- Create a new type of resource that does not require changes in the existing AGC or market systems.
- Minimize adverse impacts of regulation on conventional units in terms of their efficiency and wear and tear.

Benefits

- Better more robust and cost effective mitigation of intermittency impacts on system balancing functions.
- Reduced regulation capacity requirements for both BAs.
- Provide additional frequency responsive resource.
- Operate conventional regulating units closer to their most efficient operating point.
- Minimize wear and tear on conventional AGC units.

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Background

- Co-funded by CEC and BPA
- Contributors:
  - Study conducted by PNNL
  - CEC/CIEE
  - BPA
  - Subcontractor: Beacon Power
- A Three-Phase Project:
  - Phase I: Completed in FY 08
    - Proof of the Concept/Initial system configuring and design
  - **Phase II: Ongoing**
    - **Flywheel field tests and results analysis**
    - **Battery storage evaluation**
  - Phase III: not funded yet
    - Develop a model for an investment-based practical deployment of a WAESM system

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Specific Goals and Objectives of Phase II

- Flywheel Field Test Design and Result Analysis
  - Develop control algorithms and conduct field tests
    - Focus on **flywheel energy storage.** The **dispatchable load and distributed generation are** subject to availability of resources and affordability of experiments.
    - Now and future scenarios. (**Higher penetration**)
    - Obtain technical and performance field test data such as response time, ramping capability, losses, energy limits, and others.
  - Calculate and analyze performance characteristics.
- Battery Storage Evaluation
  - Analyze the existing opportunities for battery storage in California (market opportunities, possible technical services, advantages and disadvantages, etc.)
  - What helps and what harms the project (markets, regulations, etc.)
  - Provide recommendations

Flywheel Field Tests

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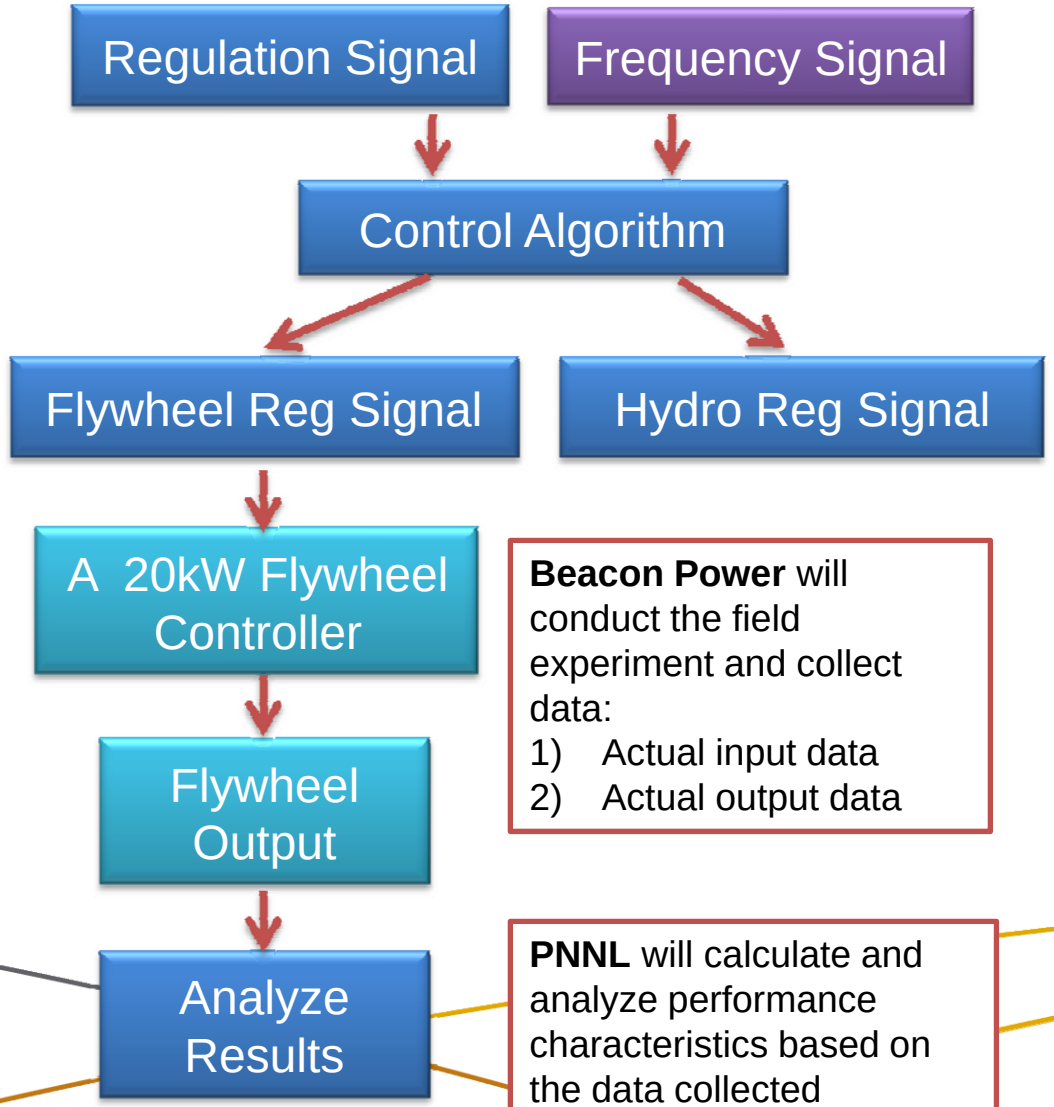
Phase II: Flywheel Field Experiments Design



PNNL work with BPA and CAISO to:

1) Collect actual regulation and frequency data
2) Create look-ahead data

PNNL will use the algorithm developed in Phase I to allocate the regulation service between hydro and flywheel.

1) A few improvements on the algorithm are needed
2) The generated flywheel reg-signals will be sent to Beacon Power for implementation

Beacon Power will conduct the field experiment and collect data:

1) Actual input data
2) Actual output data

PNNL will calculate and analyze performance characteristics based on the data collected

Phase I: Used modeling results
Phase II: Field experiments

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Data Request

	Data Type	ime ste	Start	End	Representing Conditio	File Format
CAISO	Hydro unit BLACK: POP, RegHlim, Actual operation point,RegLlim, Ramprate	4 s	25-Aug-08	31-Aug-08	CAISO summer peak	CSV, EXCEL
			8-Dec-08	14-Dec-08	BPA winter peak	
	CAISO Total: Reg-up and Reg-down, ACE, ActualWind, Actualgeneration, Actualload, RegulationServicePrice, Energy Price; LoadFollowingServicePrice		13-Apr-09	19-Apr-09	wind volatility	
BPA	A) Grand Coulee: 1) Basepoint Adjustment 2) regulation; B) Total Regulation Signals include: 1) Total Basepoint Adjustment 2) Total regulation		25-Aug-08	31-Aug-08	CAISO summer peak	
			8-Dec-08	14-Dec-08	BPA winter peak	
			13-Apr-09	19-Apr-09	wind volatility	

Battery Storage Evaluation

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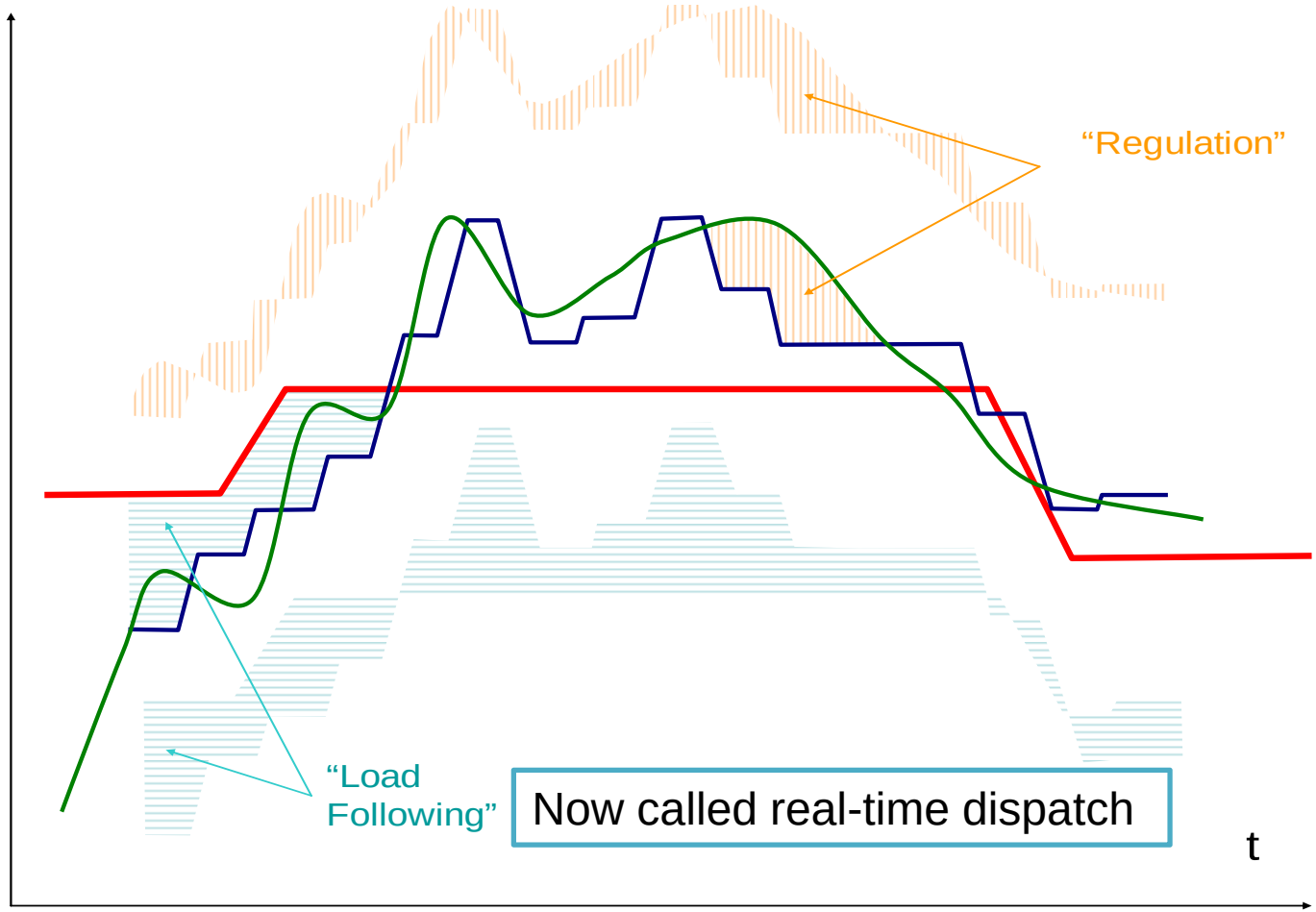
Objectives

Focusing on the battery applications under an assumption of 20% renewable penetration in 2020

- Regulation
- Load following

- Define / examine marketplace for each application
  - Market / operational conditions
  - Limitations
  - Opportunities
- Assess market potential based on battery's physical characteristics and needs of marketplace
  - Energy capacity (MWh)
  - Power rating (MW)
  - Cycling capacity
  - Economic life
  - Size

Regulation and Load Following Services



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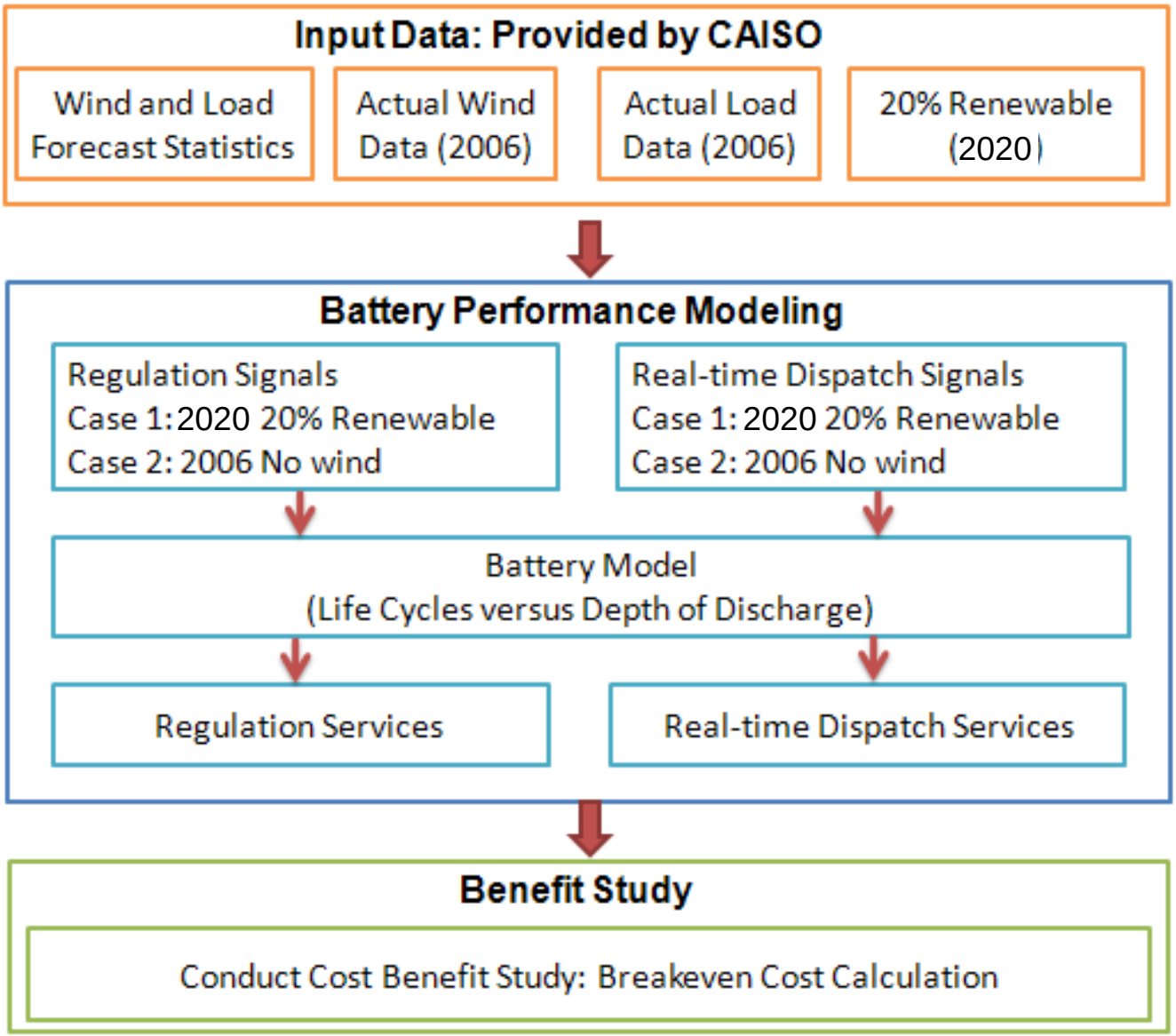
Tasks

- Evaluate PG&E Battery Storage Facility (NaS, 4 MW, 28 MWh)
  - Extend Phase I evaluation on regulation capabilities
  - Focus on load following capabilities
  - Evaluate:
    - Breakeven costs
    - Determine whether the battery's physical characteristics such as energy capacity, rated power output, lifetime, and others can appropriately support (economic, etc) the intended application.
- Identify changes in California's market, FERC regulations or NERC/ WECC Standards
  - Operating procedures and practices, control systems
  - Create feasible, economic applications for the NaS battery storage.
- Deliverable: A Summary Report on the Battery Evaluation Study

Approach: the Modeling Framework



Input Data

Modeling

Benefit Study

Cost Methodology

- Calculated breakeven analysis using standard levelized cost approach.

- Breakeven Cost / kWh =
  Annualized Capital Cost / kWh + Annual Operating Cost / kWh

- Annualized Capital Cost / kWh = Capital Cost × Recovery Factor

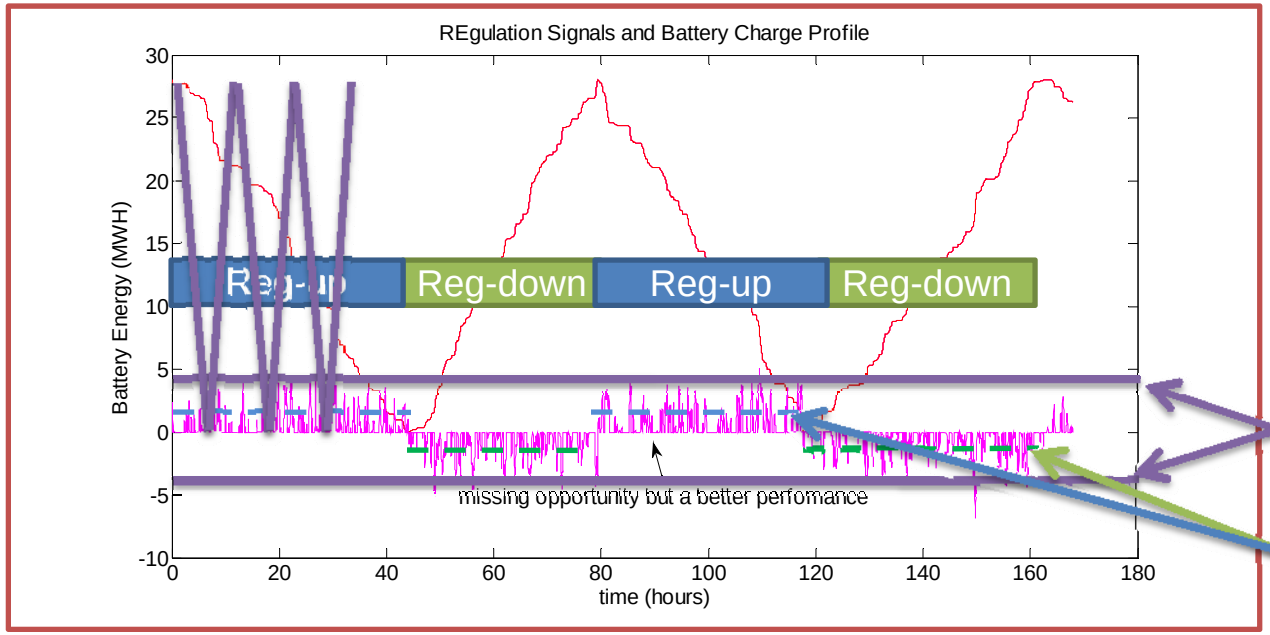
  Recovery Factor = (i*(1+i)^n)/((1+i)^n-1)
  where
  n = Battery life
  i = Discount Rate

- Annual Operating Cost / kWh = Annualized Operating Cost / annual kWh

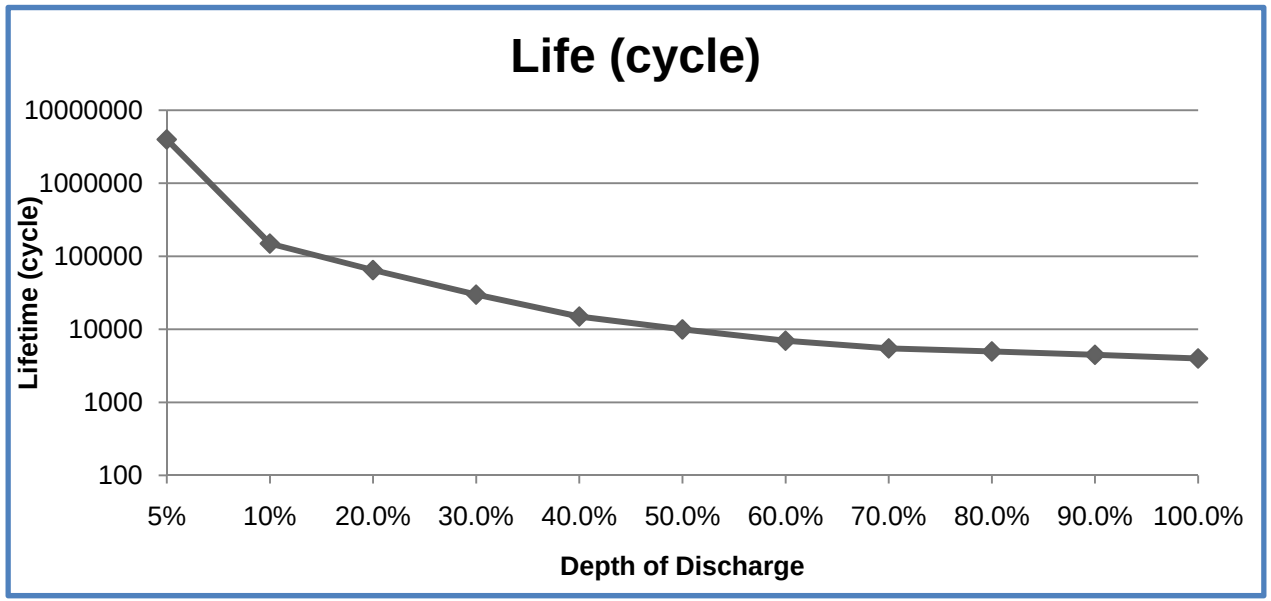
  For example: 10% × Capital Cost/Annual kWh

Assumptions

- Regulation and real time market signals are generated based on the 2006 California ISO data.
- Assume 20% renewable penetration in 2020
- Four cases: wind and no-wind; regulation and real-time dispatch.
- One directional service:
  - Battery Capacity: 28 MWh.
  - The rated power output: 4 MW.
  - The battery is fully charged when t = 0
  - The battery only takes “up” signal when discharging.
  - The battery only takes “down” signal when charging.
- Battery life cycles are determined by depth of discharge



One directional Service: better performance and control, lower utilization rate



Lifetime versus DOD (depth of discharge)

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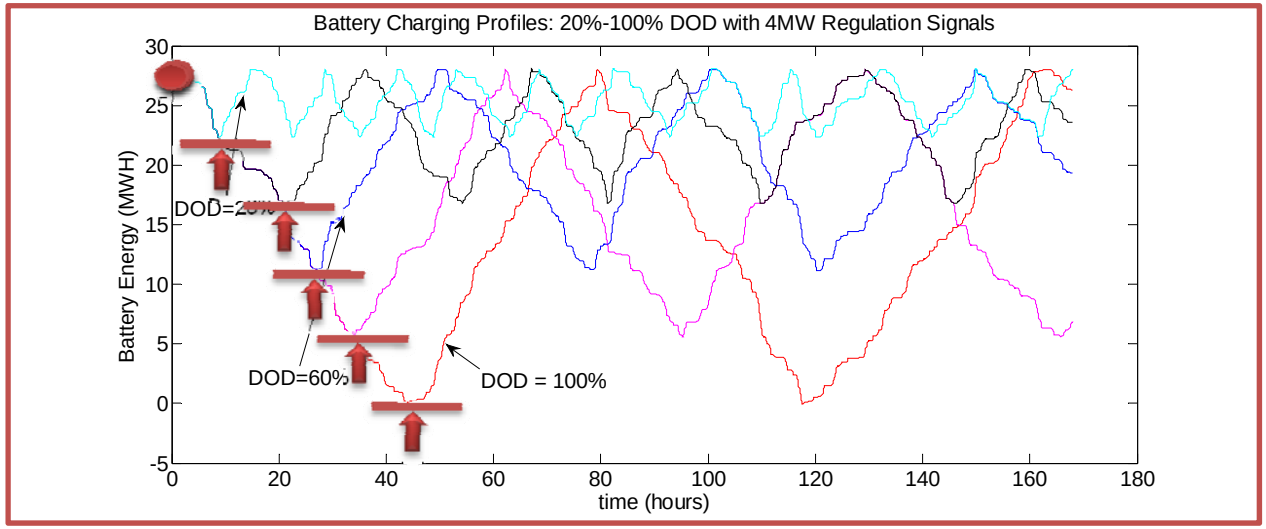
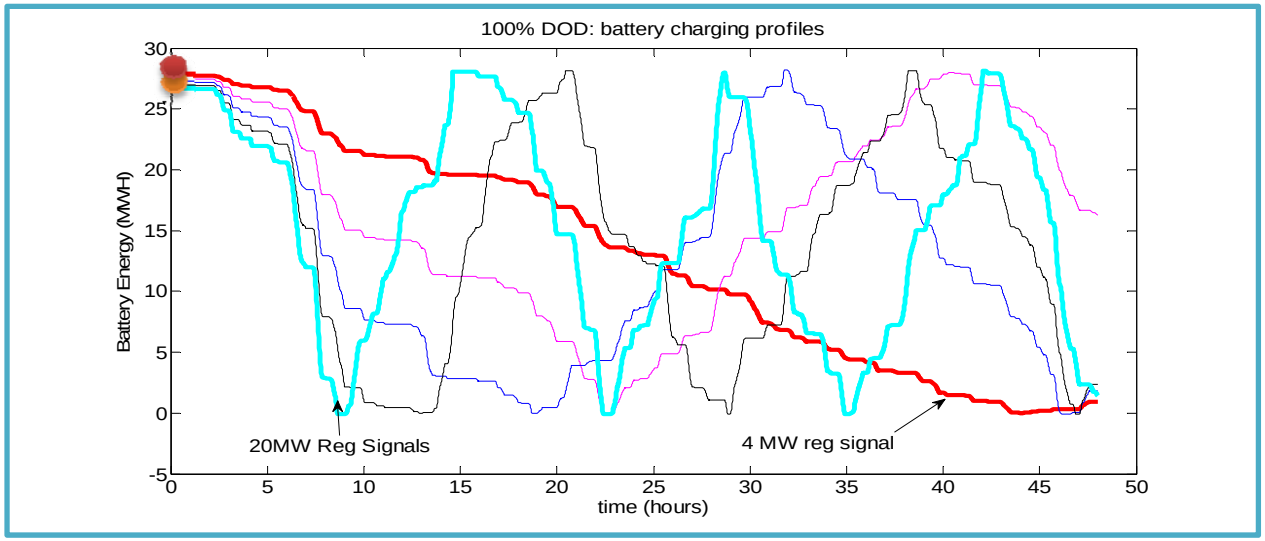


Deeper charging and discharging of battery banks results in fewer cycles.



Assume same battery capacities:
A battery with higher rated power provides more regulation services in a fixed period of time.

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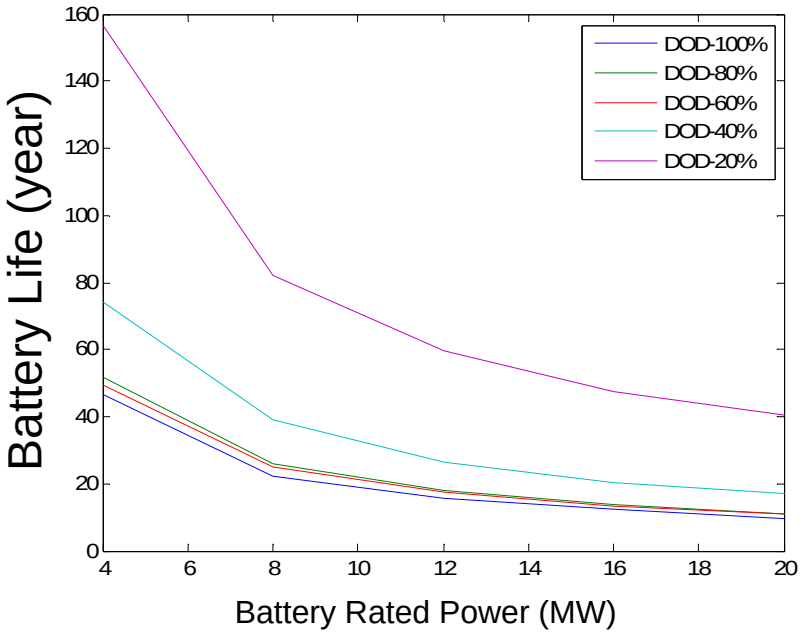
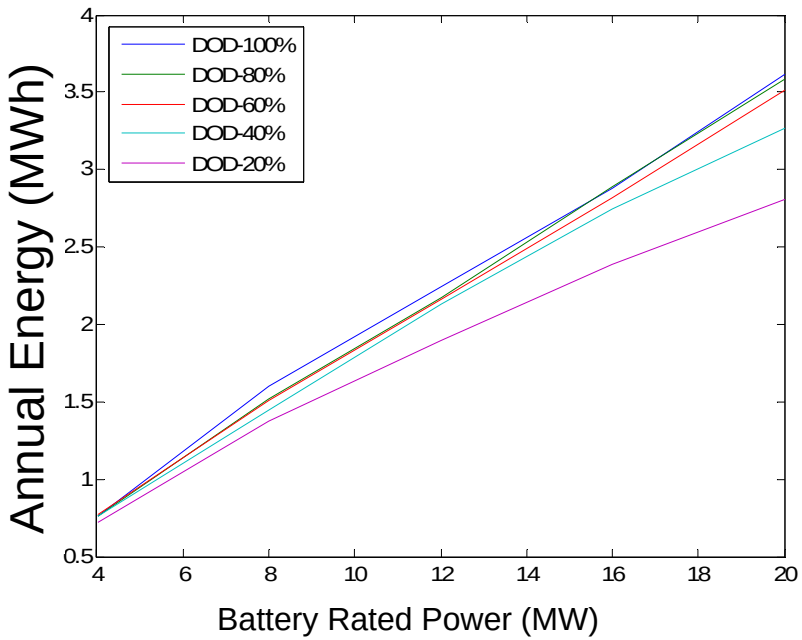
Lifetime and Annual Energy with respect to the DOD and Battery Power Ratings

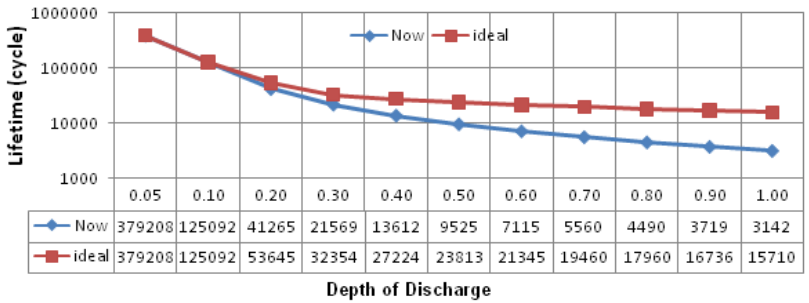




The higher the DOD, the shorter the lifetime.
The higher the battery power rating, the shorter the lifetime.

The higher the DOD and battery power rating, the higher the annual regulation or real-time market energy provided.

Improved lifecycles



Base Case With current technology			High End Breakeven Price ($/MWh)		Low End Breakeven Price ($/MWh)	
Life	DOD	Life (cycle)	0% Profit	8% Profit	0% Profit	7% Profit
20	5%	379208	15.22	23.12	7.61	11.84
20	10%	125092	23.08	35.04	11.54	17.94
20	20%	41265	34.98	53.11	17.49	27.19
20	30%	21569	44.61	67.74	22.31	34.68
20	40%	13612	53.02	80.51	26.51	41.22
20	50%	9525	60.61	92.04	30.31	47.12
20	60%	7115	67.62	102.68	33.81	52.57
20	70%	5560	74.17	112.63	37.08	57.66
20	80%	4490	80.36	122.03	40.18	62.48
20	90%	3719	86.24	130.96	43.12	67.05
20	100%	3142	91.87	139.51	45.94	71.43
Technology Improvement Prolonged Lifecycles at Higher DODs			High End Breakeven Price ($/MWh)		Low End Breakeven Price ($/MWh)	
Life	DOD	Life (cycle)	0% Profit	8% Profit	0% Profit	7% Profit
20	5%	379208	15.22	23.12	7.61	11.84
20	10%	125092	23.08	35.04	11.54	17.94
20	20%	53645	26.91	40.86	13.45	20.92
20	30%	32354	29.74	45.16	14.87	23.12
20	40%	27224	26.51	40.25	13.25	20.61
20	50%	23813	24.24	36.82	12.12	18.85
20	60%	21345	22.54	34.23	11.27	17.52
20	70%	19460	21.19	32.18	10.60	16.48
20	80%	17960	20.09	30.51	10.05	15.62
20	90%	16736	19.17	29.10	9.58	14.90
20	100%	15710	18.37	27.90	9.19	14.29

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Different Payment Methods: Pay by Capacity and Pay by Energy

		High-end Pay-by-capacity ($/MW)					Low-end Pay-by-Capacity ($/MW)					Adjusted LifeTime (Year)				
	P_{rated} (MW)	DOD					DOD					DOD				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Regulation	4	26	26	26	26	26	16	16	16	16	16	20	20	20	20	20
20% wind	8	15	14	13	13	13	9	9	8	8	8	14	16	20	20	20
	12	12	10	10	9	9	8	7	6	5	5	10	12	15	20	20
	16	10	9	8	7	7	6	6	5	4	4	8	10	12	15	20
	20	9	8	7	6	5	6	5	5	4	3	7	8	9	13	20
Regulation	4	26	26	26	26	26	16	16	16	16	16	20	20	20	20	20
No-wind	8	15	14	13	13	13	9	9	8	8	8	14	16	19	20	20
	12	12	11	10	9	9	8	7	6	6	5	9	11	13	18	20
	16	10	10	9	7	7	7	6	6	5	4	7	8	10	14	20
	20	9	9	8	7	5	6	6	5	4	3	6	7	8	11	19

		High-end Pay-by-Energy ($/MWh)					Low-end Pay-by-Energy ($/MWh)					Adjusted LifeTime (Year)				
	P_{rated} (MW)	DOD					DOD					DOD				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Regulation	4	197	206	204	198	238	101	105	104	101	122	20	20	20	20	20
20% wind	8	112	106	103	119	124	59	55	53	61	64	14	16	20	20	20
	12	89	89	86	80	87	49	47	45	41	44	10	12	15	20	20
	16	84	79	73	67	68	46	43	39	35	35	8	10	12	15	20
	20	77	71	65	60	57	43	39	35	32	29	7	8	9	13	20
Regulation	4	191	193	193	190	202	98	99	99	97	104	20	20	20	20	20
No-wind	8	108	103	101	101	111	57	54	52	52	57	14	16	19	20	20
	12	88	85	78	74	77	48	45	41	38	40	9	11	13	18	20
	16	79	73	68	63	61	44	40	37	33	31	7	8	10	14	20
	20	73	67	62	56	52	41	37	34	30	27	6	7	8	11	19

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Different Battery Power Ratings

	P_{rated} (MW)	Breakeven Price (8% Profit) ($MWh) DOD 1	0.8	0.6	0.4	0.2	Utilization Rate (P_{ave}/P_{rated}) DOD 1	0.8	0.6	0.4	0.2	Adjusted LifeTime (Year) DOD 1	0.8	0.6	0.4	0.2
Regulation 20% Renewables	4	197	206	204	198	238	0.18	0.17	0.17	0.18	0.15	20	20	20	20	20
	8	112	106	103	119	124	0.18	0.18	0.17	0.15	0.14	14	16	20	20	20
	12	89	89	86	80	87	0.18	0.16	0.15	0.15	0.13	10	12	15	20	20
	16	84	79	73	67	68	0.15	0.15	0.15	0.14	0.13	8	10	12	15	20
	20	77	71	65	60	57	0.15	0.15	0.15	0.14	0.12	7	8	9	13	20
Real-time Dispatch 20% Renewables	4	164	169	183	203	270	0.15	0.15	0.14	0.12	0.09	20	20	20	20	20
	8	97	101	114	135	189	0.13	0.12	0.11	0.09	0.07	19	20	20	20	20
	12	82	83	90	108	148	0.11	0.10	0.09	0.08	0.06	15	19	20	20	20
	16	74	73	77	95	125	0.10	0.09	0.08	0.07	0.05	13	16	20	20	20
	20	68	68	70	83	110	0.09	0.08	0.07	0.06	0.05	11	14	19	20	20
Regulation No-wind	4	135	137	137	135	144	0.18	0.18	0.18	0.18	0.17	20	20	20	20	20
	8	77	73	71	72	79	0.18	0.18	0.18	0.17	0.16	14	16	19	20	20
	12	63	60	55	52	55	0.18	0.17	0.17	0.16	0.15	9	11	13	18	20
	16	56	52	48	45	43	0.17	0.17	0.17	0.16	0.14	7	8	10	14	20
	20	52	48	44	40	37	0.17	0.17	0.16	0.16	0.14	6	7	8	11	19
Real-time Dispatch No-wind	4	177	179	201	229	303	0.14	0.14	0.12	0.11	0.08	20	20	20	20	20
	8	108	115	128	151	219	0.12	0.11	0.10	0.08	0.06	20	20	20	20	20
	12	86	90	101	121	172	0.10	0.09	0.08	0.07	0.05	16	20	20	20	20
	16	77	79	87	109	147	0.09	0.08	0.07	0.06	0.04	14	17	20	20	20
	20	72	74	78	96	129	0.08	0.07	0.06	0.05	0.04	12	16	20	20	20

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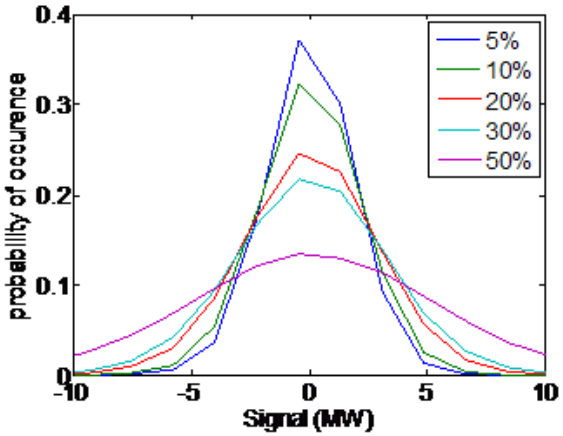
Different Regulation and Real-time Signals

		Breakeven Price (High End)					Breakeven Price (Low End)				
	Signal Outliers	DOD					DOD				
		1	0.8	0.6	0.4	0.2	1	0.8	0.6	0.4	0.2
Regulation	5%	197	206	204	198	238	101	105	104	101	122
	10%	175	177	176	171	203	90	90	90	87	104
20%	20%	138	140	135	148	160	71	72	69	76	82
Renewables	30%	131	129	127	143	146	67	66	65	73	75
	50%	112	105	101	112	116	59	55	52	57	60
Realtime	5%	231	238	257	285	381	118	122	132	146	195
Dispatch	10%	205	217	228	270	355	105	111	117	138	182
	20%	174	181	195	231	308	89	93	100	118	158
20%	30%	151	159	177	204	278	77	82	91	104	142
Renewables	50%	135	142	155	180	239	70	73	79	92	123
Regulation	5%	191	193	193	190	202	98	99	99	97	104
No-wind	10%	175	172	175	172	185	90	88	89	88	95
	20%	144	144	143	149	156	74	74	73	76	80
	30%	132	131	129	140	144	68	67	66	72	74
	50%	117	112	108	113	119	61	58	55	58	61
Realtime	5%	249	251	283	322	426	128	129	145	165	218
Dispatch	10%	217	226	254	285	387	111	116	130	146	198
No-wind	20%	183	201	219	250	339	94	103	112	128	174
	30%	167	183	193	224	312	86	94	99	115	160
	50%	143	147	161	192	267	73	75	82	98	137



The probability distribution functions of the regulation signals

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Conclusions

- Improved lifecycles: If manufacturers can improve the NaS battery's number of lifecycles at high DODs, the breakeven prices will drop significantly for high DOD cases.
- Under the *pay-by-energy* scheme for regulation and real-time dispatch services, for a 4 MW, 28 MWh NaS battery to provide regulation and real-time dispatch services, breakeven prices are above $100/MWh, making the operation not economical in the California market.
- The results indicate that if the 4 MW battery provides one-directional regulation service, the high-end cost will be $26/MW and the low-end cost will be $16/MW. In the California market, this means the NaS battery may become marginally profitable.

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Conclusions

- If the battery rated power can be increased, the breakeven price will drop significantly because the battery is able to handle a broader range of signals. However, after 12 MW, the price drop is not significant, but the battery life is shortened dramatically. Therefore, based on the current lifecycle-DOD curve, it is beneficial for the battery manufacturer to increase the battery rated power output up to 8 or 12 MW, which will result in a breakeven price drop of 1/2 to 1/3.
- If we let 50% of the regulation or real-time signals that are outside the NaS battery's rated capability be supplied by the flywheel, which has a high power output but less energy storage capacity, the NaS battery service will be more economical and efficient.

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