Designing Battery Energy Storage Systems for Reliability

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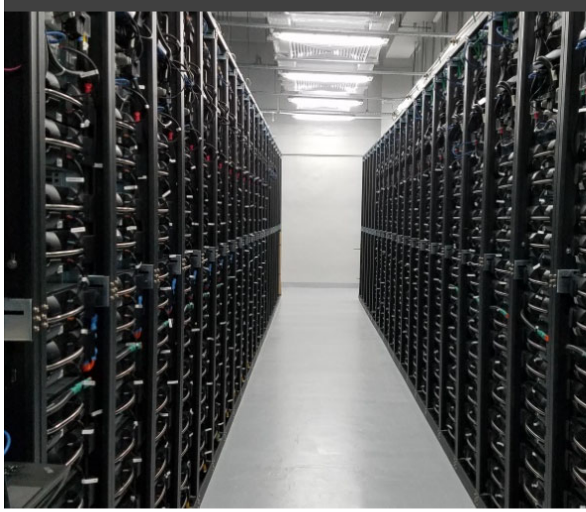
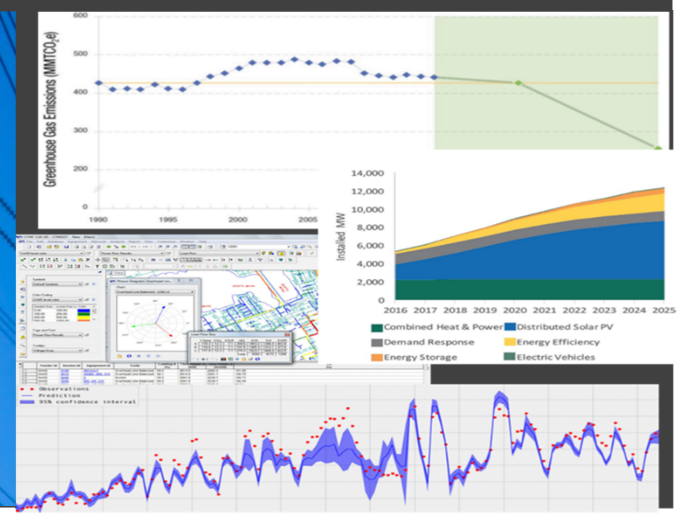
Brian Curran, MPR Associates





Agenda

Introduction

- What is the Issue?

Design of a Typical BESS

- Components, Groups, Hierarchy

Reliability Tools for Analyzing BESSs

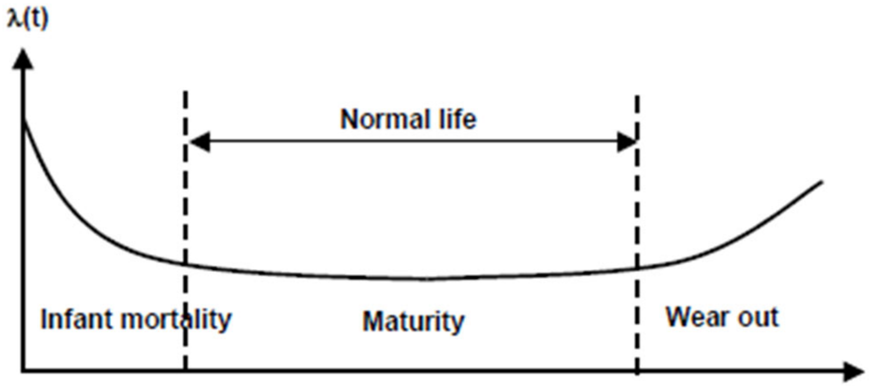
- Failure Rates, Reliability Networks
- Reliability vs. Availability
- Series, Parallel, K-out-of-N, Monte Carlo

Reliability for a Typical BESS

- 8 Hour, 7 Day
- Time Variant Output: Year 1, Year 4

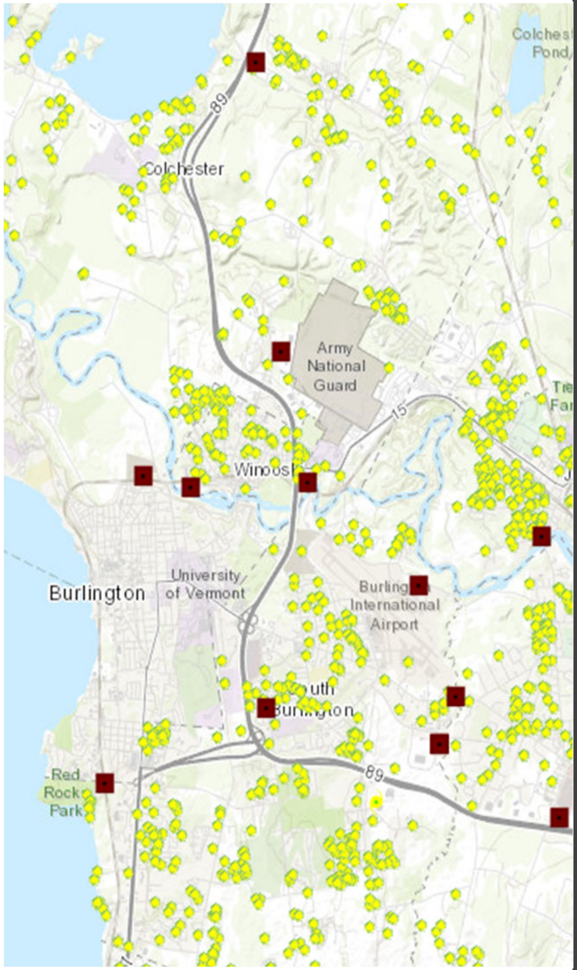
Availability of Typical BESS

- Quasi-Hybrid Markov Chain Monte Carlo



Introduction

- The energy storage industry is growing rapidly and the continued large scale deployment of distributed generation will continue to drive this growth.
  - Lithium-ion battery based storage is the enabling technology behind the current surge in growth.
- Application and use of energy storage systems by utilities and transmission operators is also maturing.
  - Once viewed primarily as generation assets, battery energy storage systems are now being deployed as economical non-wires alternatives (NWAs) for traditional substation and distribution system upgrades.
- BESSs are typically supplied with guarantees of facility Availability
  - BESS Availability and Facility Reliability are both important for BESS deployment, but they are not the same and need to be separately evaluated.

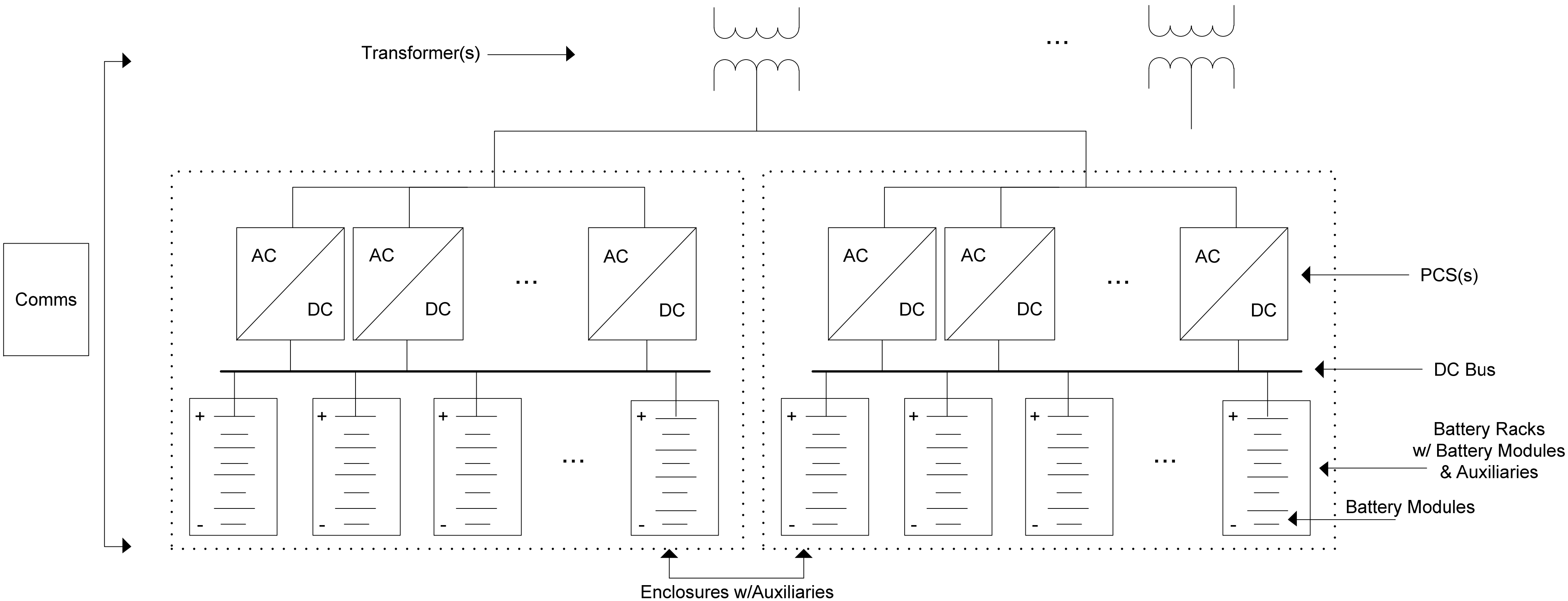


Design of a Typical BESS

- A typical BESS is a modular assembly of many similar components configured into similar blocks, with each block consisting of:
  - Battery modules consisting of many battery cells
  - Battery racks consisting of many battery modules
  - Battery enclosures consisting of many battery racks, a common DC bus, and provisions for environmental control and communication
  - Power Conversion Systems (PCS) for DC / AC conversion
  - Medium voltage collector transformers
  - Auxiliary power supply and transformer
  - Site Controller, Energy Management, and Data Acquisition Systems
  - Other peripherals based on facility design
    - DC/DC converters
    - High voltage GSU

Design of a Typical BESS – Topology Variants of a 5MW / 20 MWH BESS

- Number of Enclosures
- PCS: Large Skid Mount vs String Inverter
- MV transformers: PCS Integrated or Standalone
- Configuration of Battery Cells 1P16, 2P16, etc.
- Battery Rack and Module Cooling Designs: Air vs. Water Cooling



Introduction → **Design of a Typical BESS** → Reliability Tools → Reliability of a Typical BESS → Availability of a Typical BESS

Tools for Evaluating Reliability

- Components with a constant failure rate are modeled using an exponential probability density function which uses a constant failure rate

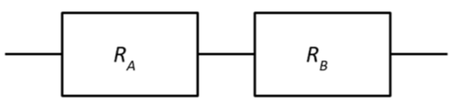
Part or System Failure Rate: λ_p

Component Reliability: $R(t) = e^{(-\lambda p * t)}$

Mean Time to Failure, MTTF: $MTTF = 1 / \lambda_p$

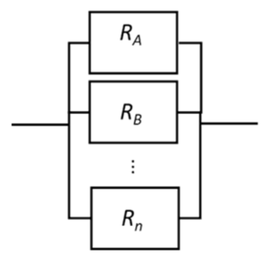
- Reliability networks convert a physical system into a reliability network model

Series Reliability Networks



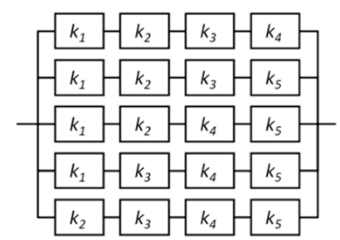
$$R_s = R_A * R_B * \ldots R_N$$

Parallel Reliability Networks



$$R_s(t) = 1 - \prod_{i=1}^{n} [1 - R_i(t)]$$

K-out-of-N Reliability Network



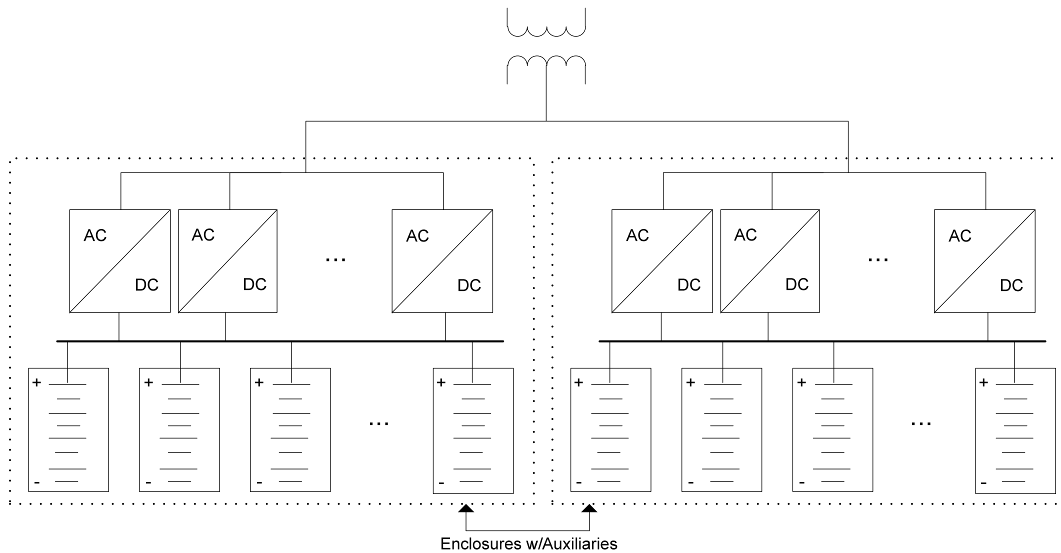
$$R_s = \sum_{i=k}^{n} \binom{n}{i} R^i (1 - R)^{n-i}$$

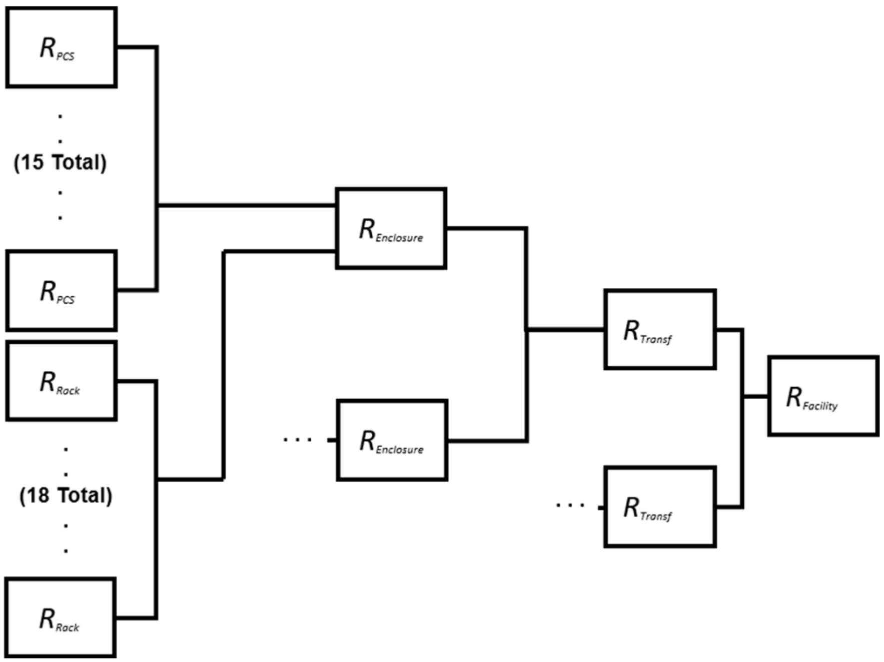
Tools for Evaluating Reliability

- Complex system consisting of series, parallel, and hierarchical networked components with independent failure mechanisms may be analyzed using a Monte Carlo method.
  - This method evaluates component states (i.e. in-service or failed) by comparing the component's reliability, which is the probability that a particular component's failure time is greater than its operating time interval, to a random number.
- Consequences of equipment failure can be assigned to each components.
- Component failures over an analyzed time period are aggregated into a combined effect on facility output power.
- Impact to facility output power based on random component failures is calculated.

Tools for Evaluating Reliability

Electrical SLD,
Communications SLD,
& Container Design Drawings





Translated into a Hierarchical Reliability Network Suitable for Monte Carlo Analysis

Reliability of a Typical BESS – Process for Monte Carlo Analysis

1. Aggregate equipment into reliability networks with common consequences of failure.
2. Develop reliability network for the BESS and select and reliability time period.
   - Reliability Period ex: 8 hours, 7 days, etc.
3. Idenitfy failure rates for each reliability network and calculate reliability of each reliability network.
4. Assign random number between 0 and 1 to each reliability block and compare to facility reliability.
   - If random number exceeds reliability, equipment is considered failed and the consequence is subtracted from facility output.
5. Determine the most likely facility output capacity in consideration of all components that are failed.
6. Repeat for thousands of iterations and plot histogram of most likely facility output.
7. Repeats steps 3-6 for alternative reliability periods, as appropriate.

Reliability of a Typical BESS – Basic Facility Specification

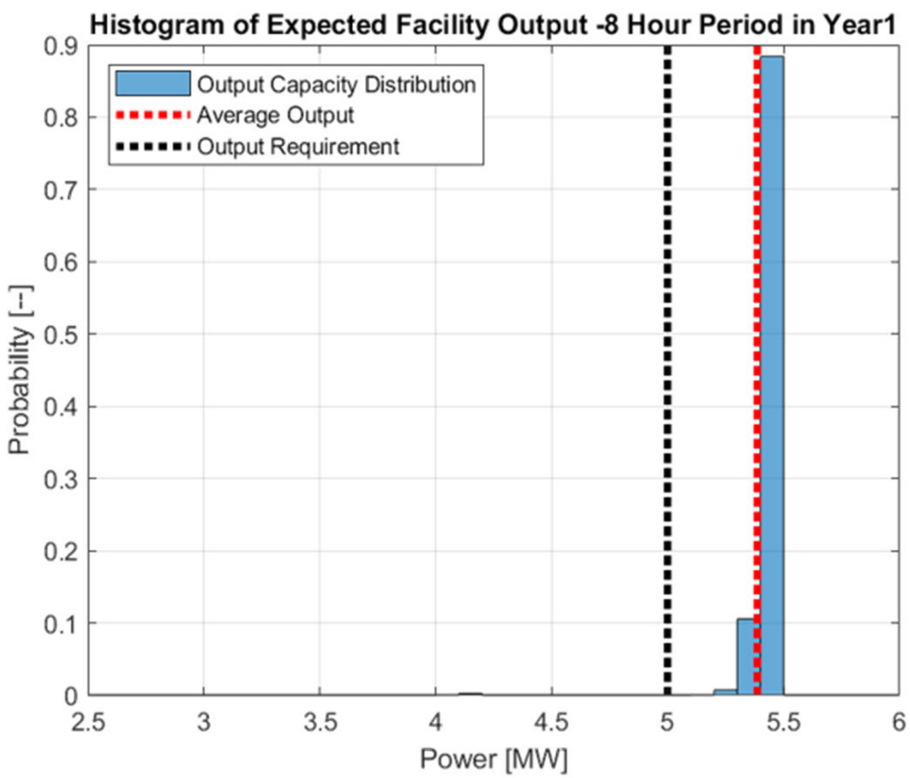
Specification of 5MW / 20MWH BESS Facility			
Equipment / Facility Ratings			
Facility Power Rating (MW)	5.0	PCS Transformer (kVA)	2750
Facility Energy (MWH)	20	PCS Rating (kVA)	90
Rack Energy (kWH)	300	C Rate	0.25[1]
Facility Design			
Number of Feeders	1	BOL Energy (kWH)	21600
Battery Cells / Module	17	BOL MFO (kW)	5400
Modules / Rack	18	PCS / Enclosure	15
Rack Power (kW)	75	Total Number of PCS	60
Racks / Enclosure	18	Number of Transformers	2
Enclosure Energy (kWH)	5400	Number of Feeders	1
Number of Enclosures	4		

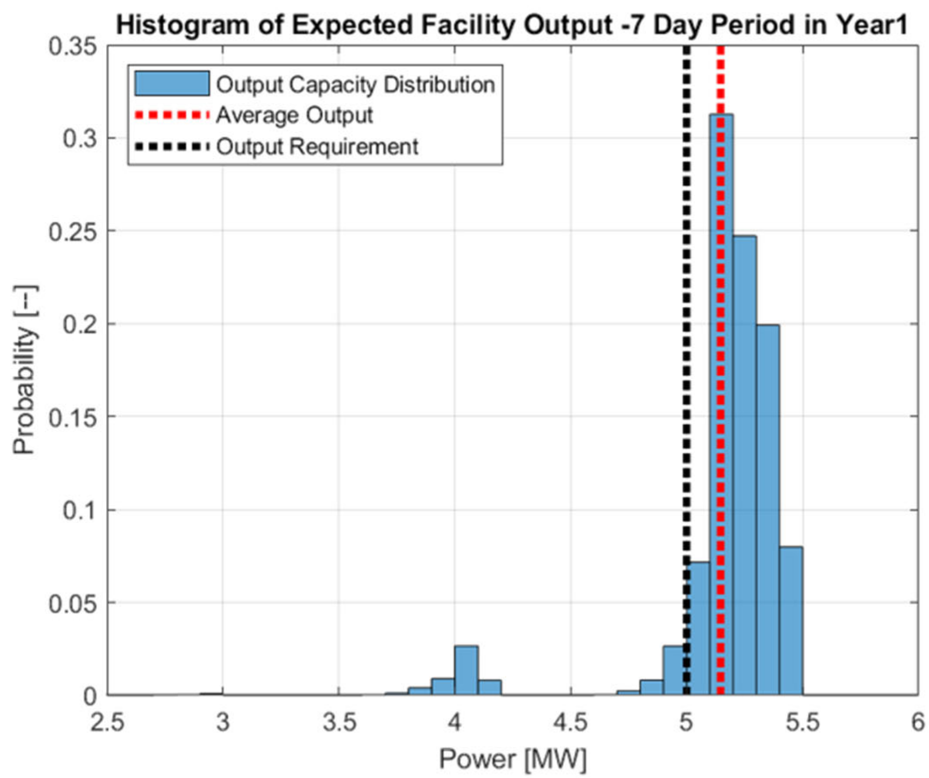
[1] Facility C-Rate is the ratio of the rated facility output power (5MW) and the battery energy capacity (20MWH).

Equipment Group	Failure Rate (Failures/10^6 Hours)	Reliability	
		8 Hour	1 Week
Battery Rack	200.0	0.9984	0.967
String PCS	7.0	0.9994	0.9875
Battery Enclosure	75.0	0.9999	0.9988
Transformer	1.0	1	0.9998
Facility	5.0	1	0.9992

Summary of Equipment Failure Categories		
Category	Description	Consequence at BOL
1	Failed Battery Rack	75 kW
2	Failed PCS	90 kW
3	Failed Container	1350 kW
4	Failed Transformer	2700 kW
5	Failed Site Ethernet	Entire Facility Capacity

Reliability of a Typical BESS – Most Likely Facility Capacity





Introduction → Design of a Typical BESS → Reliability Tools → **Reliability of a Typical BESS** → Availability of a Typical BESS

Reliability of a Typical BESS – Worked Example Observations & Conclusions

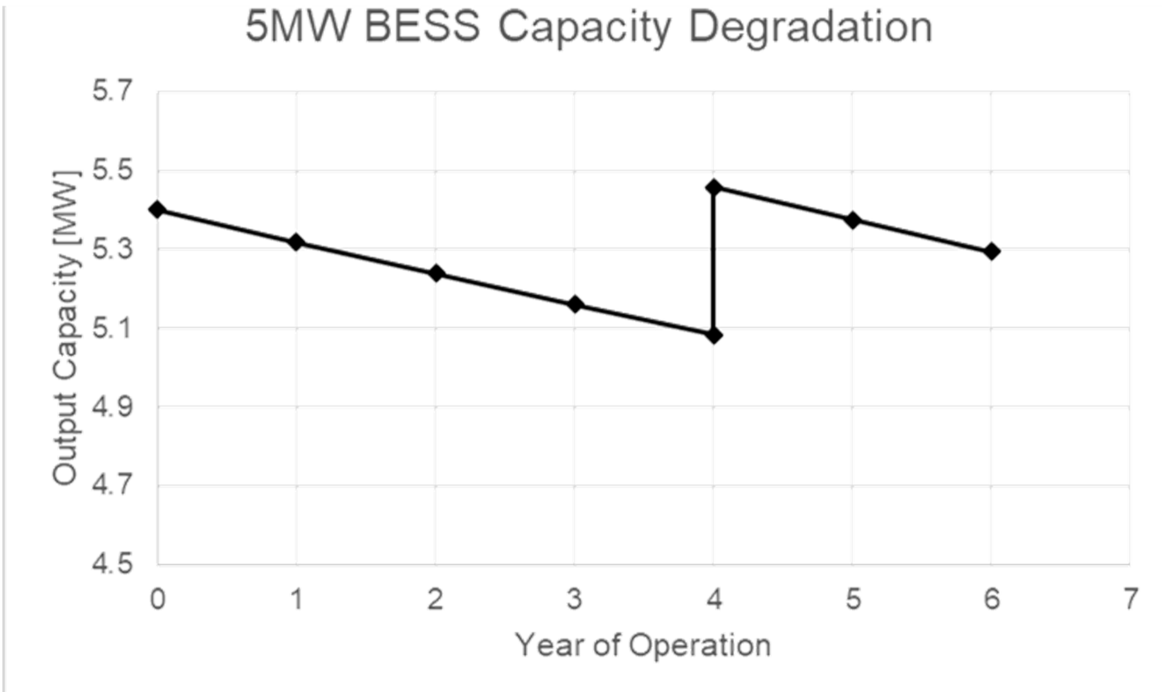
- The average most likely output capacities are 5.39 MW and 5.15 MW for the 8 hour and 1 week reliabilities, respectively.
  - The BESS is expected to satisfy the average output requirement of 5MW for both reliability durations.
- The likelihood of the average most likely output capacity exceeding the output requirement of 5MW is 99.7% and 91.9% for the 8 hour and 1 week reliabilities, respectively.

Summary of Equipment Group Contributions to BESS Expected Output Degradation

Equipment	Number of Reliability Blocks	Most Likely Number of Failures	Consequence of Failure	Contribution to Facility Output Capacity
Facility	1	0.0011	5000 kW	5.5 kW
Transformer	2	0.0005	2500 kW	1.3 kW
Enclosure	4	0.04855	1250 kW	***60.7 kW***
PCS	60	0.06925	90 kW	6.2 kW
Battery Rack	72	2.31135	75 kW	***173 kW***

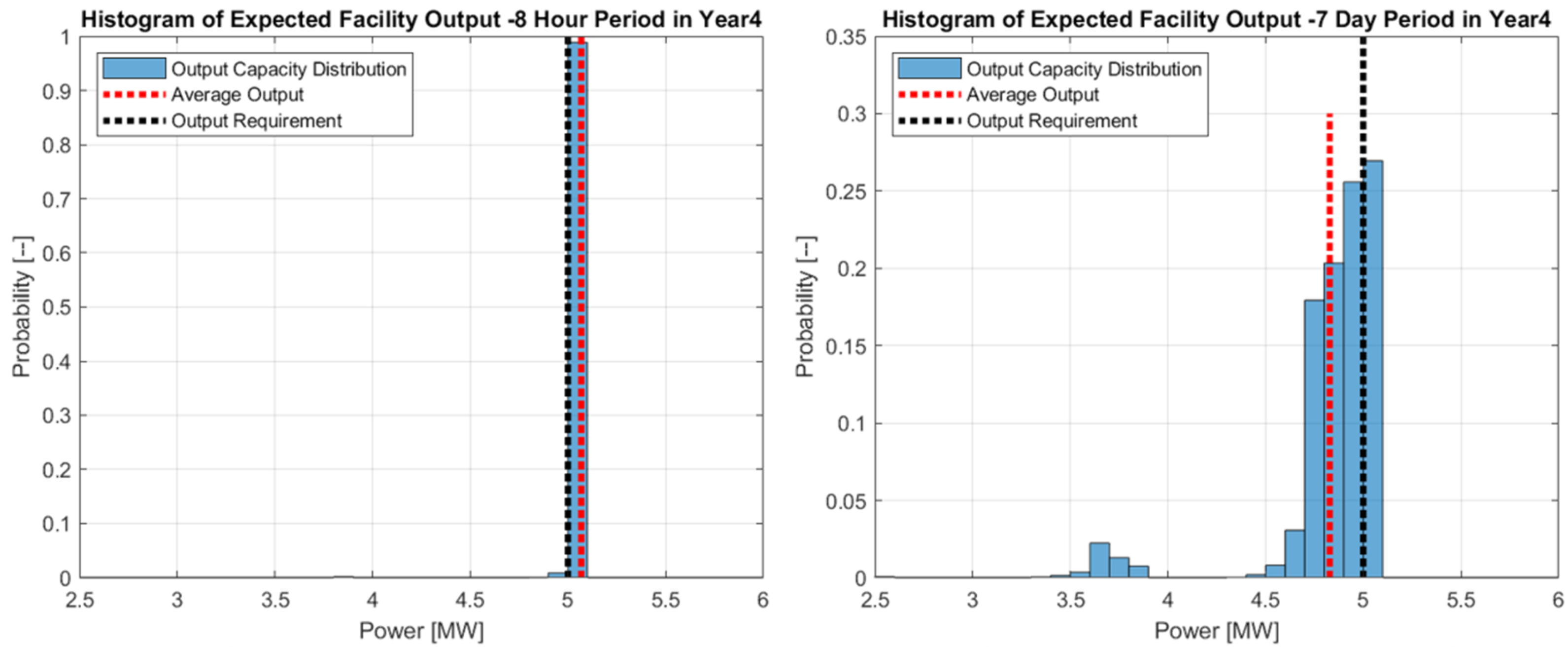
Reliability of a Typical BESS – Worked Example Time Dependency

- Capacity degradation is modeled by adjusting consequences of failure for different years according to facility degradation curve.
  - Framework for reviewing degradation curve suitability.
- What are the most likely facility outputs for 8 hour and 1 Week reliability periods in Year 4?



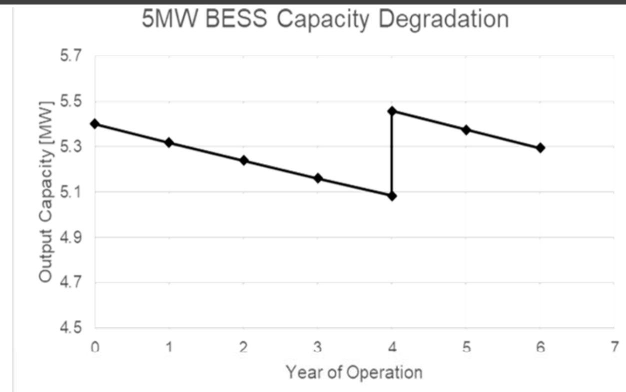
Reliability of a Typical BESS – Worked Example Observations & Conclusions

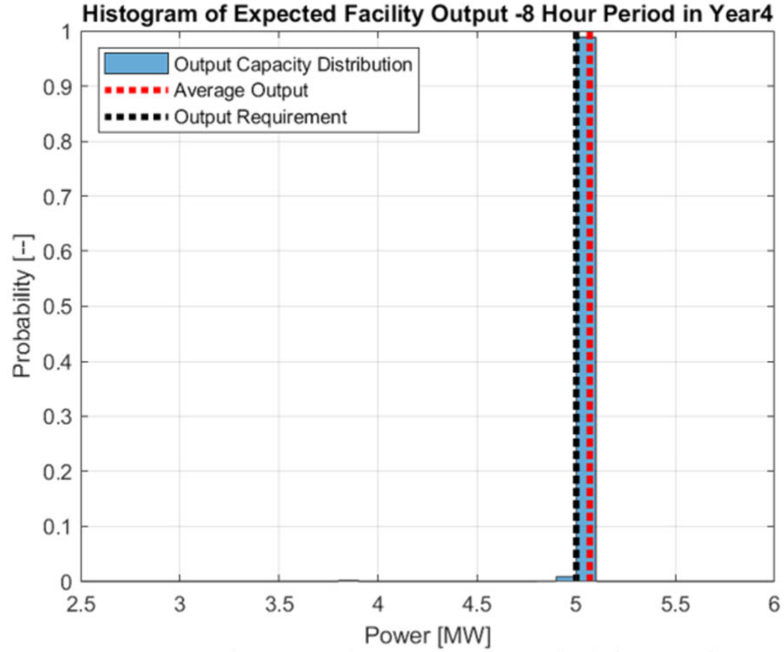
- The average most likely output capacities are 5.1 MW and 4.8 MW for the 8 hour and 1 week reliabilities, respectively.
- The likelihood of the average most likely output capacity exceeding the output requirement of 5MW is 98.8% and 26.7% for the 8 hour and 1 week reliabilities, respectively.
- Battery augmentation and overbuild is the single biggest factor in satisfying reliability informed power and energy capacity obligations!

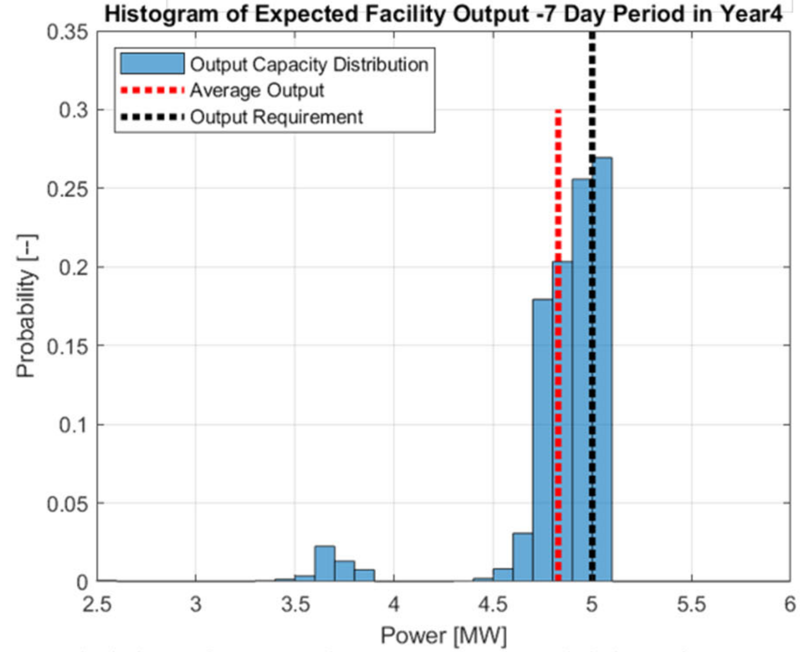


Reliability of a Typical BESS – Worked Example Time Dependency

- Capacity degradation is modeled by adjusting consequences of failure for different years according to facility degradation curve.
- Framework for reviewing degradation curve suitability.







Introduction ⟶ Design of a Typical BESS ⟶ Reliability Tools ⟶ **Reliability of a Typical BESS** ⟶ Availability of a Typical BESS

Availability of a Typical BESS

- Utilities, Developers, and Suppliers are primarily concerned with availability
  - Most commercial agreements have requirements for BESS availability
- The Monte Carlo approach described above can be used as part of a quasi-hybrid Markov chain Monte Carlo analysis (quasi-MCMC).
  - Equipment repair times can be catalogues and managed to minimize downtime
- Modify reliability analysis to include a memory for equipment that has failed:
  - Perform a Monte Carlo run, identify failed equipment
  - Mark equipment as out of service for its repair duration
  - Continue iterating Monte Carlo runs: continue removing failed equipment and restore equipment that has satisfied its repair time
  - Many iterations of this approach yield a consistent facility output power capacity that is some fraction of rated capacity

Questions?

Brian Curran
MPR Associates
bcurran@mpr.com