Energy Storage as a Reliable Alternative to Diesel Generators in Critical Power Applications

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Why Consider Energy Storage For Critical Power?

Diesel Generators have provided reliable critical power for decades – but DGs are considered "dirty" technology

Grid-scale Energy Storage Systems are new and relatively un-proven – but are considered "clean" technology

DG and ESS – Pros and Cons

DG

- Proven technology
- Wide knowledge base for O&M
- **Inexpensive $**
- Extended run-time

ESS

- Clean technology
- Pair with renewables for 100% GHG-free generation
- Reduced O&M complexity
- **Market participation can offset cost**

DG

- GHG emissions
- Complex O&M
- **AQMD limits total run-time, market participation**

ESS

- New technology, still working out kinks
- Complex control systems
- Limited run-time
- **Expensive $$$**

How do we compare DG and ESS for critical power applications?

Where do we start?

We Start With Reliability

Reliability

The ability of a component or system to perform required functions under stated conditions for a stated period of time.

Failure Rate

The number of failures of a component and/or system per unit exposure time. Commonly expressed in failures/hour.

Availability

A = 1 – Failure Rate

A = 1 – Probability of Failure

MTBF

Mean Time Between Failures

MTTR

Mean Time To Repair

Pxyz(t)

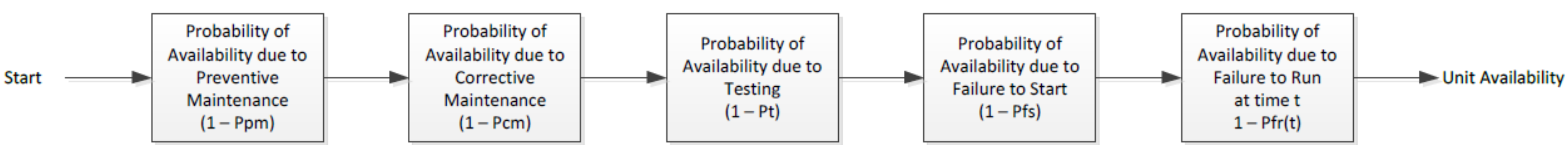
Probability of Failure

What Factors Into the Reliability Calculation?

Metric	Description
Ppm	Probability of preventive maintenance
Pcm	Probability of corrective maintenance
Pt	Probability of testing
Pfs	Probability of failure to start
Pfr(t)	Probability of failure to run

$$Availability = 1 - Failure\ Rate$$

$$Pfr(t) = 1 - e^{\frac{-t}{MTBF}}$$



Diesel Generator – Example Reliability Calculation

Prob of Prev Maint	1.180%	Ppm	98.820%	Probability of Availability due to Preventive Maint
Prob of Corr Maint	0.500%	Pcm	99.500%	Probability of Availability due to Corrective Maint
Prob of Testing	0.200%	Pt	99.800%	Probability of Availability due to Testing
Prob of Failure to Start	0.50%	Pfs	99.50%	Probability of Availability due to Successful Start
			97.639%	Time Invariant Probability of 1 Generator being Available

General MTBF 1200 hr

Failure to Run - Based on MTBF **Pfr(t)**

Hour	**Pfr(t)**	***1 - Pfr(t)***	***Single Generator Rel***
1	0.08%	99.92%	***97.56%***
2	0.17%	99.83%	***97.48%***
4	0.33%	99.67%	***97.31%***
8	0.66%	99.34%	***96.99%***
10	0.83%	99.17%	***96.83%***
36	2.96%	97.04%	***94.75%***

DG fails to meet 95% reliability criteria at 36 hours of operation – extended run-time advantage is limited.

Energy Storage System – Example Reliability Calculation

Prob of Prev Maint	0.550%	**Ppm**	**99.450%**	Probability of Availability due to Preventive Maint
Prob of Corr Maint	0.820%	**Pcm**	**99.180%**	Probability of Availability due to Corrective Maint
Prob of Testing (Switching)	0.140%	**Pts**	**99.860%**	Availability due to testing of switchgear, transition, etc.
Prob of Testing (Cycling)	0.300%	**Ptc**	**99.700%**	Availability due to cycling battery to test capacity, etc.
Prob of Failure to Start	0.0006%	**Pfs**	**99.9994%**	Probability of Availability due to Successful Start
			98.200%	Time Invariant Probability of 1 ESS being Available

	General MTBF	6972 hr	
	Failure to Run - Based on MTBF	**Pfr(t)**	
Hour	**Pfr(t)**	***1 - Pfr(t)***	***Single***
1	0.0143%	99.99%	***98.19%***
2	0.0287%	99.97%	***98.17%***
4	0.0574%	99.94%	***98.14%***
8	0.1147%	99.89%	***98.09%***
10	0.1433%	99.86%	***98.06%***

For the same run-time, the ESS is more reliable than the DG!

But What About Market Participation?

Primary Use Case

- Critical Power
- Must meet minimum required reliability

→ Generates no revenue

→ Requires asset to sit idle

Secondary Use Cases

- Capacity
- Voltage/Frequency Regulation
- Load Following

→ Generates revenue

→ Can value stack

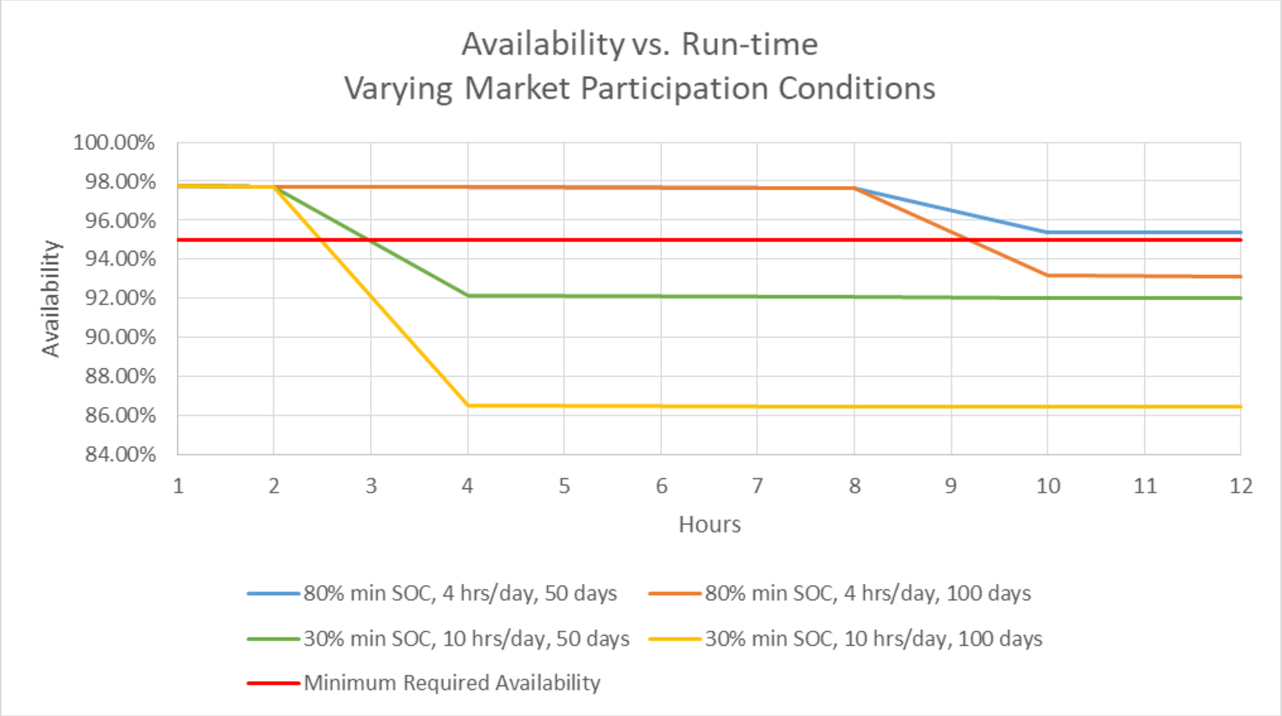
Market Participation Probability

$$P_{mk}(t) = \frac{(10\,\frac{hrs}{event}) * 50\frac{events}{year}}{8760\frac{hrs}{year}} = 5.71\%$$

- If SOC is kept above a minimum during market participation, and capacity exists to serve critical load, Availability is 100% → Probability of Failure = 0%.
- If SOC is allowed to drop below the required minimum capacity to serve critical load, availability is a function of time spent participating in the market, or **A = 1 – Pmk(t)**.

Availability to serve critical function is directly affected by conditions of market participation.

Total Availability – Market Participation



Conditions

- 10-hr system
- Varying min SOC during market participation

Requirements:

- 10-hr critical load support
- >95% availability

If SOC is kept above a minimum threshold, and market participation is limited, total availability can remain > 95%.

	General MTBF	6972	Total Availability	
	Failure to Run			
Hours	Pfr(t)	1-Pfr(t)	Hours	Availability
1	0.0143%	99.9857%	1	97.7447%
2	0.0287%	99.9713%	2	97.7306%
4	0.0574%	99.9426%	4	97.7026%
8	0.1147%	99.8853%	8	97.6466%
10	0.1433%	99.8567%	10	93.1611%
12	0.1720%	99.8280%	12	93.1344%

Future Work

What if we wanted to utilize all of the available capacity of the ESS?

What if we wanted to calculate potential market participation?

Potential Market Participation

$$Available\ Hours\ of\ Market\ Participation = Pmkt(t) * 8760\ \frac{hr}{yr}$$
$$= \left[1 - \frac{Minimum\ Availability}{Acomp * Afr(t)}\right] * 8760\ \frac{hr}{yr}$$

Minimum Availability: Defined by the requirements. Typically > 95%.

Acomp: Comprehensive *Time-invariant* Availability. Availability due to testing, maintenance, failure to start.

Afr(t): Availability due to probability of failure to run. Based on required primary use-case duration.

Pmkt(t): Probability of market participation given a defined t-hour critical load requirement.

Potential Market Participation

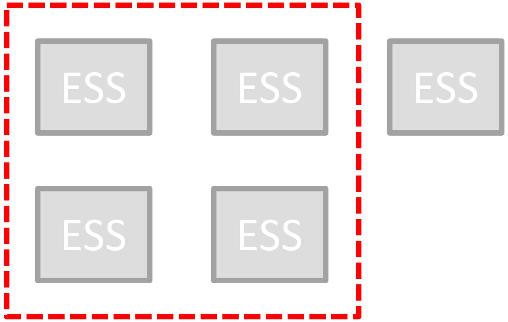
$$Pmkt(10) = \left[1 - \frac{95\%}{97.62\%}\right] * 8760 = [1 - 97.32\%] * 8760 = 235\ hr$$

- Independent of system duration
- No additional capacity required
- SOC allowed to go to 0% during market participation
- Less than 10 days/year
- Not likely to affect CapEx in long run
- Need a way to increase revenue

How do we *Increase* Potential Market Participation?

$$Rsys(N, M, R) = \sum_{r=N}^{M} \binom{M}{r} R^r (1-R)^{M-r}$$

$$Rsys(N, N+1, R) = (N+1)R^N(1-R) + R^{N+1}$$



Example N = 4, M = 5
Only need 4 out of 5 to serve critical load

For N+1 configurations, this increases overall system reliability immensely.

Increasing Potential Market Participation

Minimum Availability Requirement, N=1, M=2

95%

	Market Availability	Probability of Market	Available Hours/Year
1	95.031%	4.969%	435.3
2	95.032%	4.968%	435.2
3	95.032%	4.968%	435.2
4	95.033%	4.967%	435.1
10	95.033%	4.967%	435.1

This tells us that with one additional ESS "unit" we can increase total system reliability to allow market participation up to 435hrs/year.

In Summary

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DG

- Proven technology
- Wide knowledge base for O&M
- Inexpensive $
- Extended run-time

ESS

- Clean technology
- Pair with renewables for 100% GHG-free generation
- Reduced O&M complexity
- **Market participation can offset cost**
- **Higher reliability than DG**

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DG

- GHG emissions
- Complex O&M
- AQMD limits total run-time, market participation
- **MTBF ultimately limits extended run-time**

ESS

- New technology, still working out kinks
- Complex control systems
- Limited run-time
- Expensive $$$

With our framework, we can calculate the availability to participate in energy markets given equipment reliability data and use-case definition.

What's next?

- Expand ESS to further N-out-of-M configuration, N+2, N+3, etc.
- Consider ESS reliability in non-critical applications
- Financial quantification
    - Market revenue
    - GHG offset/deferral
    - Traditional distribution asset deferral
    - Paypack period for ESS investment

Optimizing market participation based on primary use-case definition and overall system reliability optimizes total cost of ownership of ESS.

Questions

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