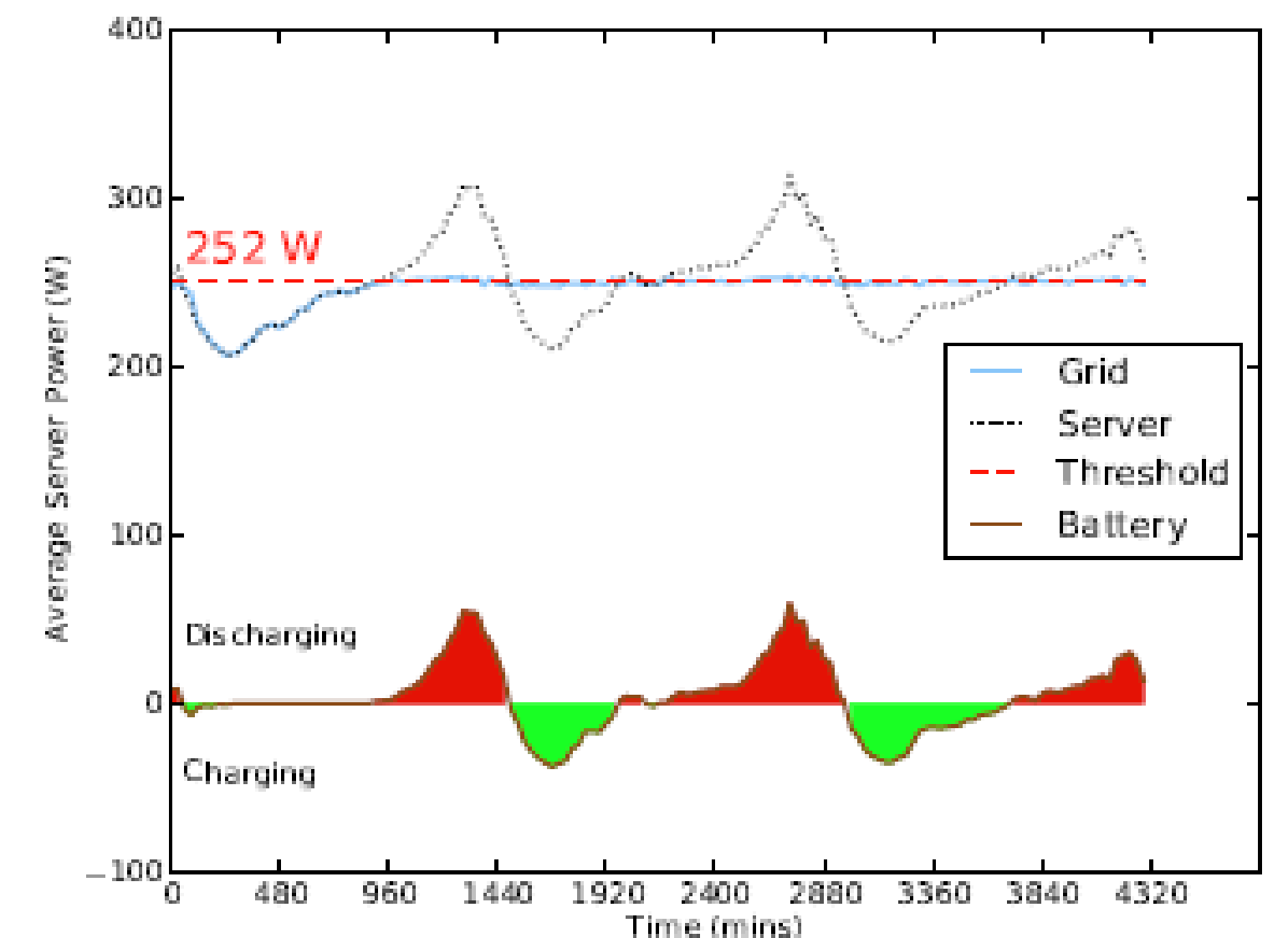
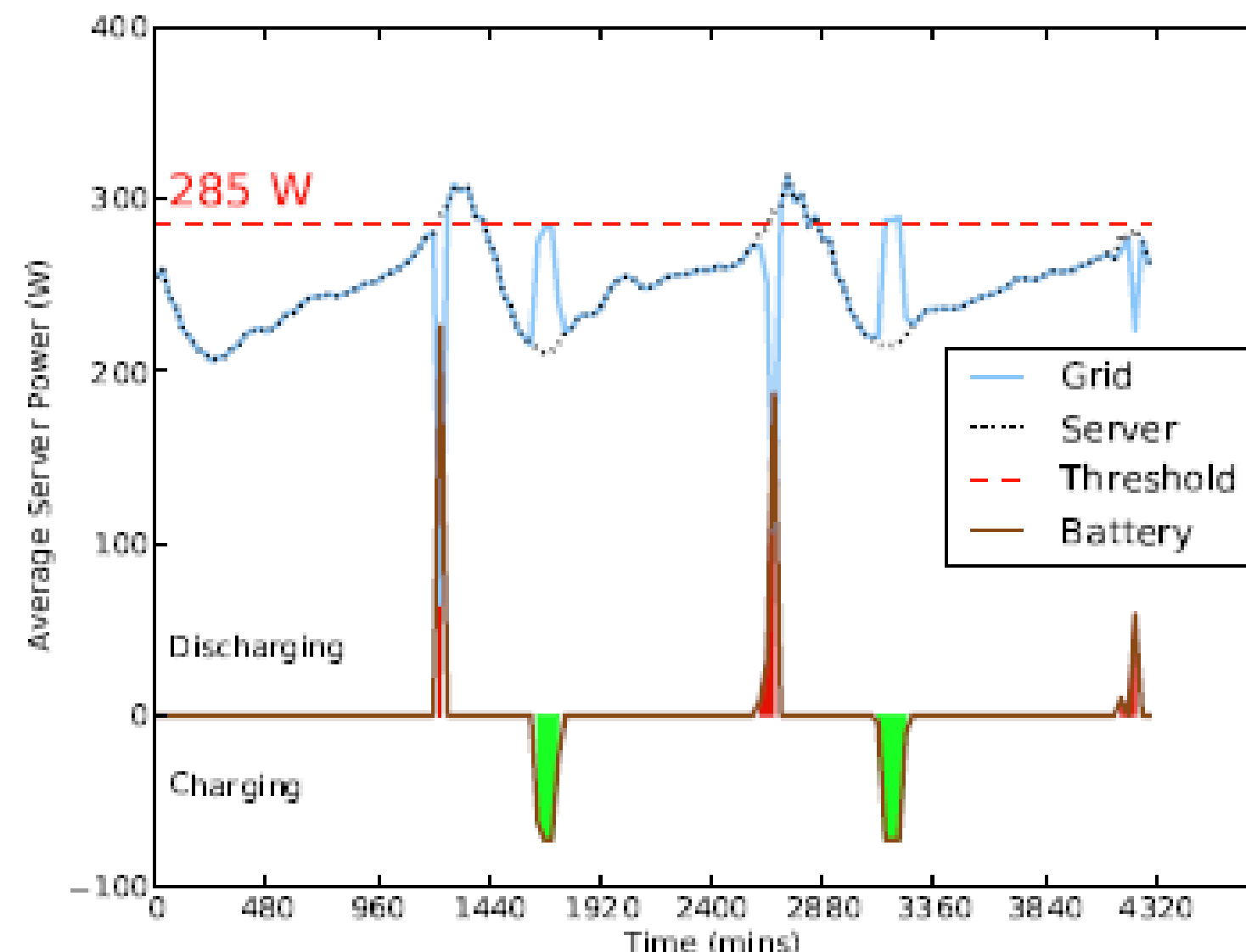
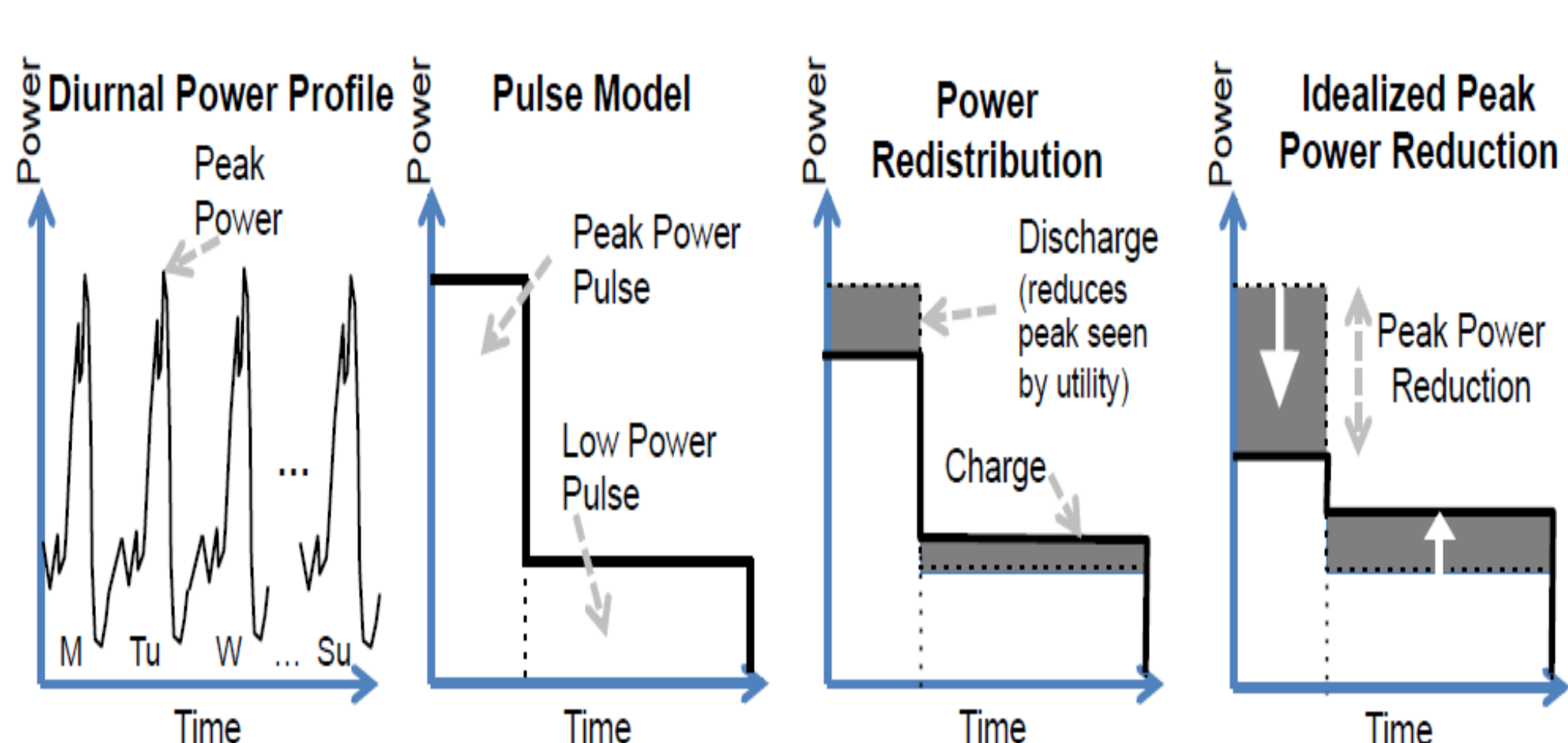


Distributed Battery Control to Improve Peak Power Shaving Efficiency in Data Centers

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 †UCSD, ‡Google

Initial Study

✓ Stored energy in batteries can be used to cap peak power in data centers



Distributed UPS with cluster coordination has:

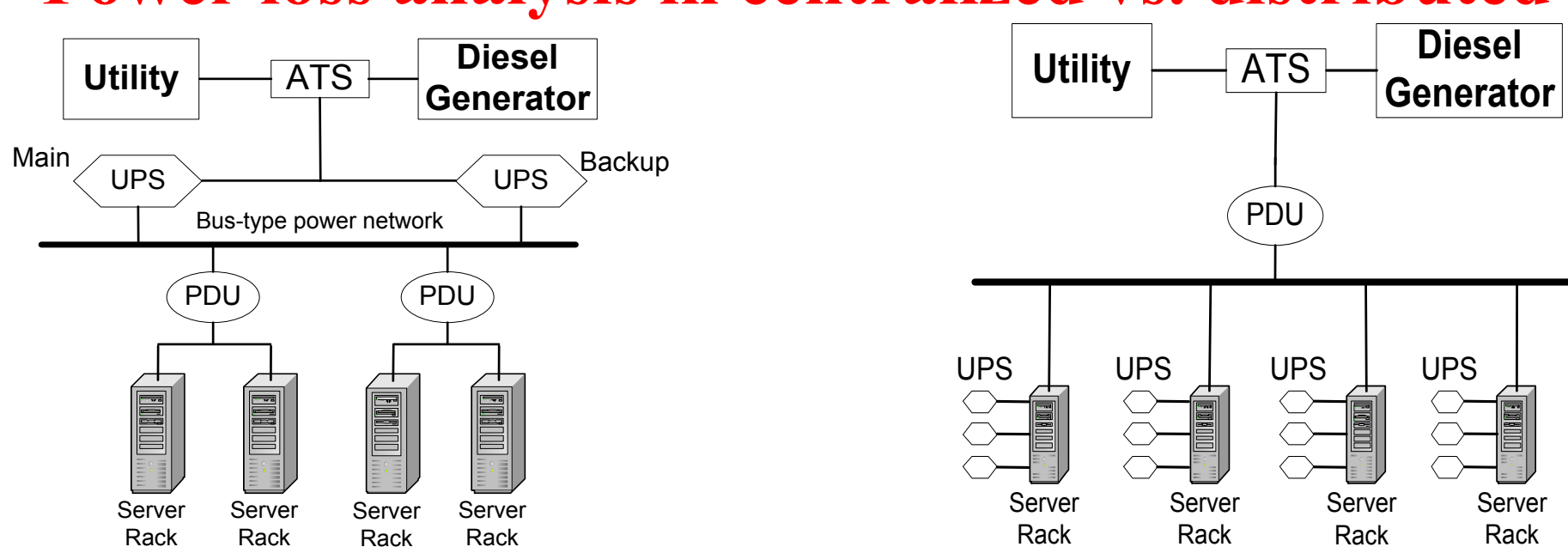
- 1.5x increase in profit per server vs. centralized
- Peak power reduction of 19% → 23% more servers → 6.2% reduction in TCO/server
- No performance overhead

Centralized UPS

Distributed UPS w/ cluster level control

Detailed Model

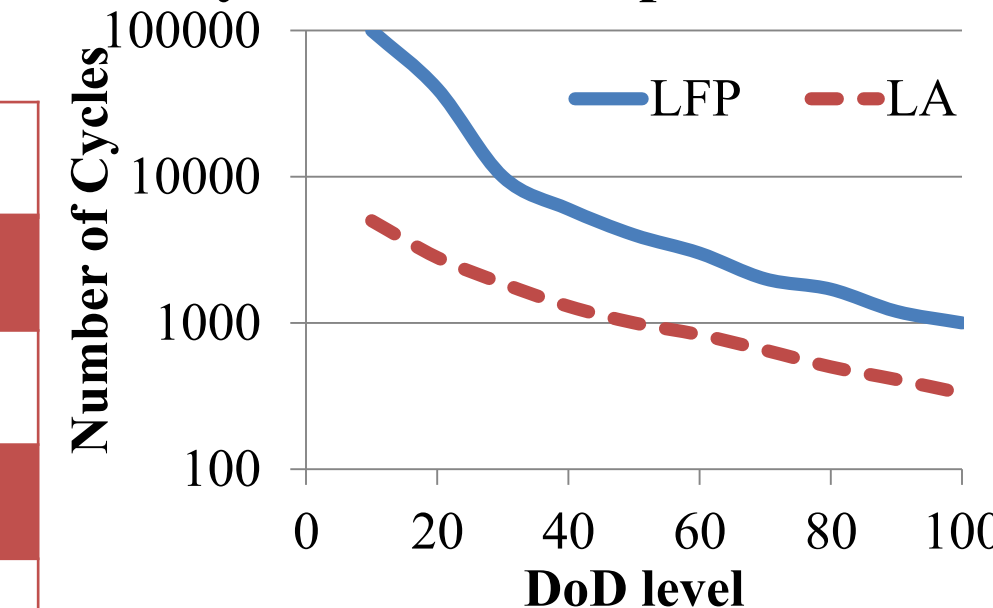
✓ Power loss analysis in centralized vs. distributed



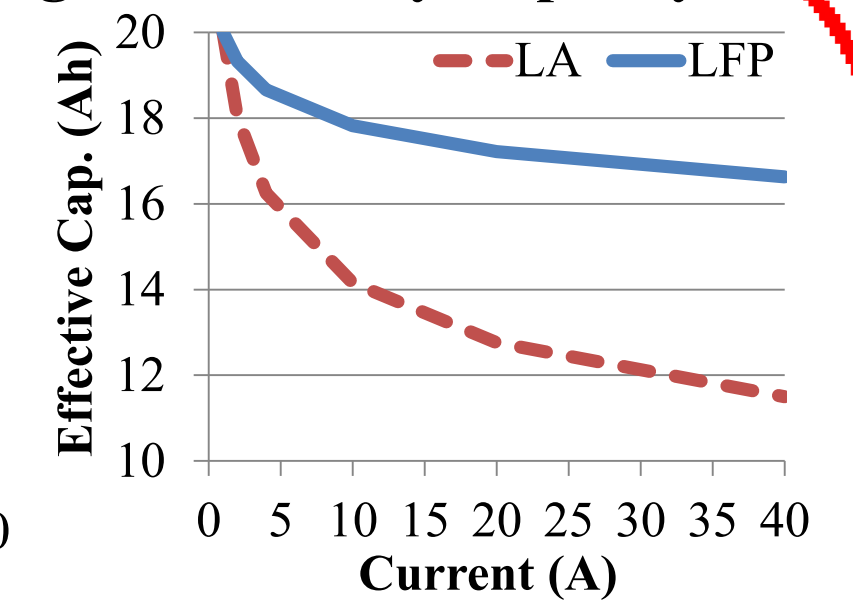
✓ Equipment efficiency (at full load)

	UPS	PDU	PSU	Total
480V AC	89.2%	93.2%	75.4%	62.6%
480V AC - high	96.2%	99.5%	90.2%	86.3%
380V DC	96%	99.5%	91.7%	87.6%
48V DC	92.8%	99%	91.5%	84%

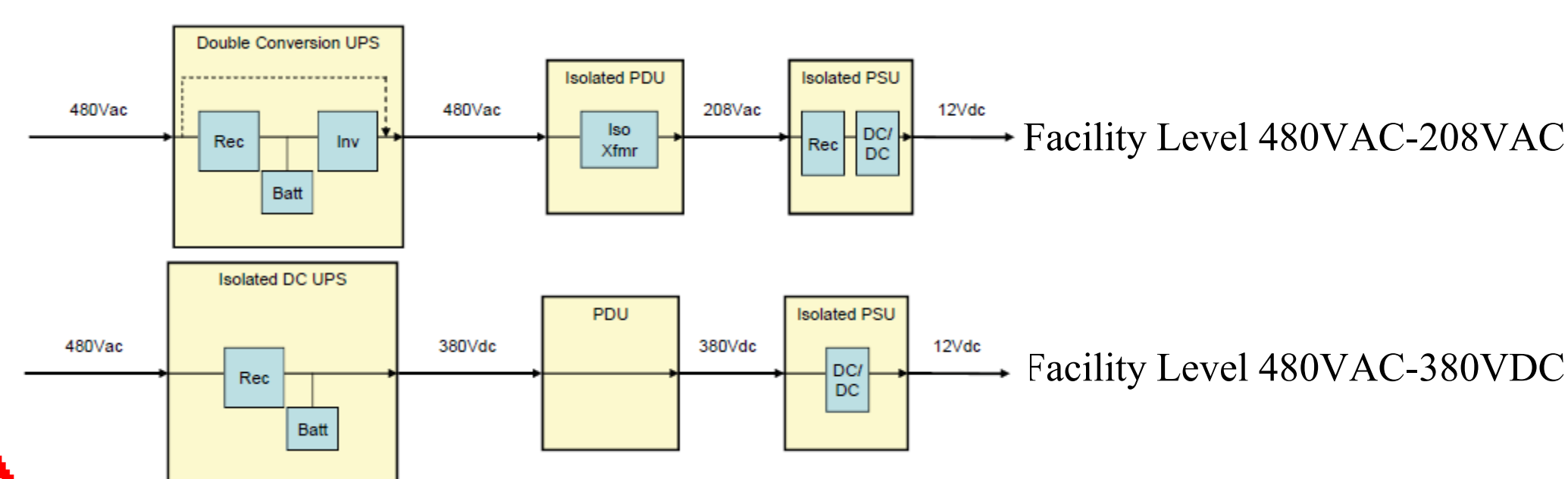
Battery lifetime vs. depth-of-discharge



Battery Capacity

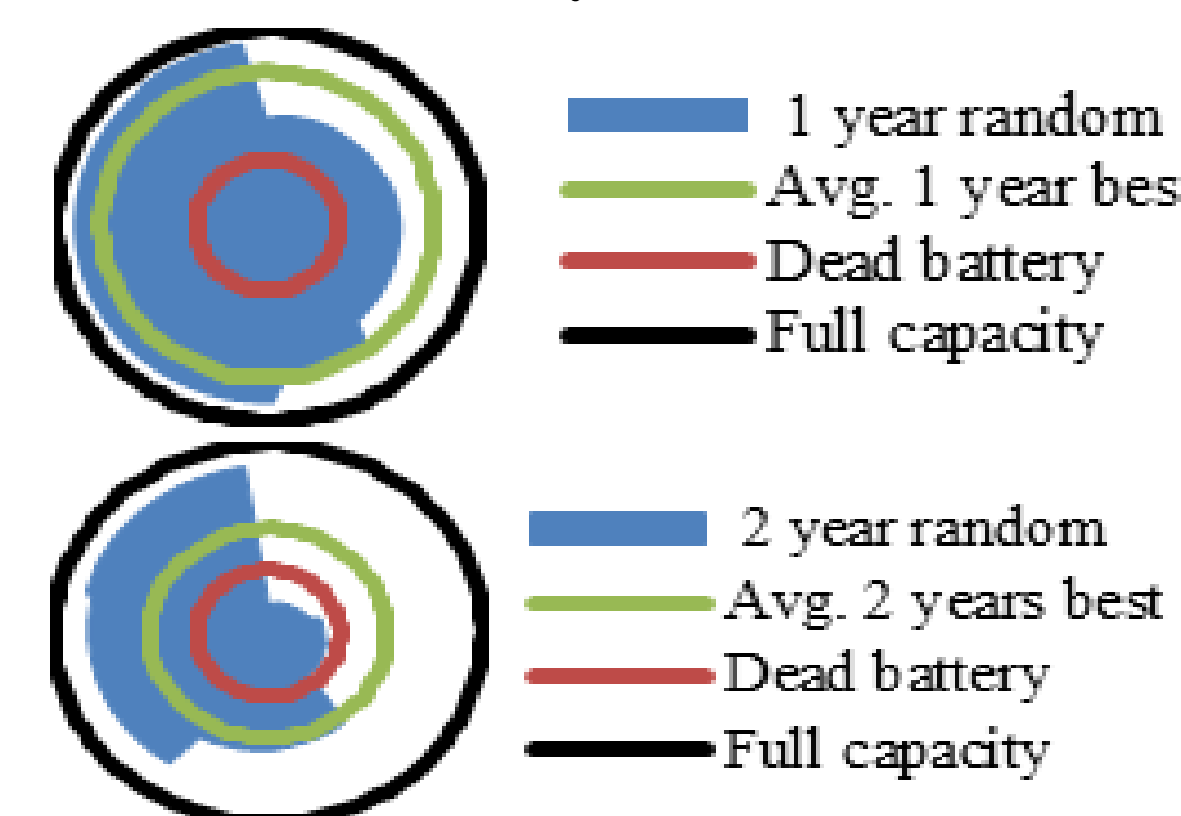


✓ AC vs. DC power delivery architectures



✓ Battery State-of-Charge and State-of-Health Analysis

1. Using a detailed battery model
2. Effects of non-uniform battery discharge on battery lifetime
3. Effects of high discharge currents
4. Battery lifetime (SoH) variation
5. Need for battery coordination



Battery Lifetime comparison with a simple vs. detailed battery model

	LA	LFP
Simple	3 yrs	10 yrs
Detailed	1.4 yrs	4.1 yrs

Battery Configuration Study

Goal: Improve the overall lifetime of all the batteries by maximizing total battery State-of-Health (SoH)

- ✓ Random & iterative battery selection policies have low performance
- ✓ Best solution is possible with global communication which leads to large communication overhead

Realistic implementation: Create battery control groups and communicate among the groups

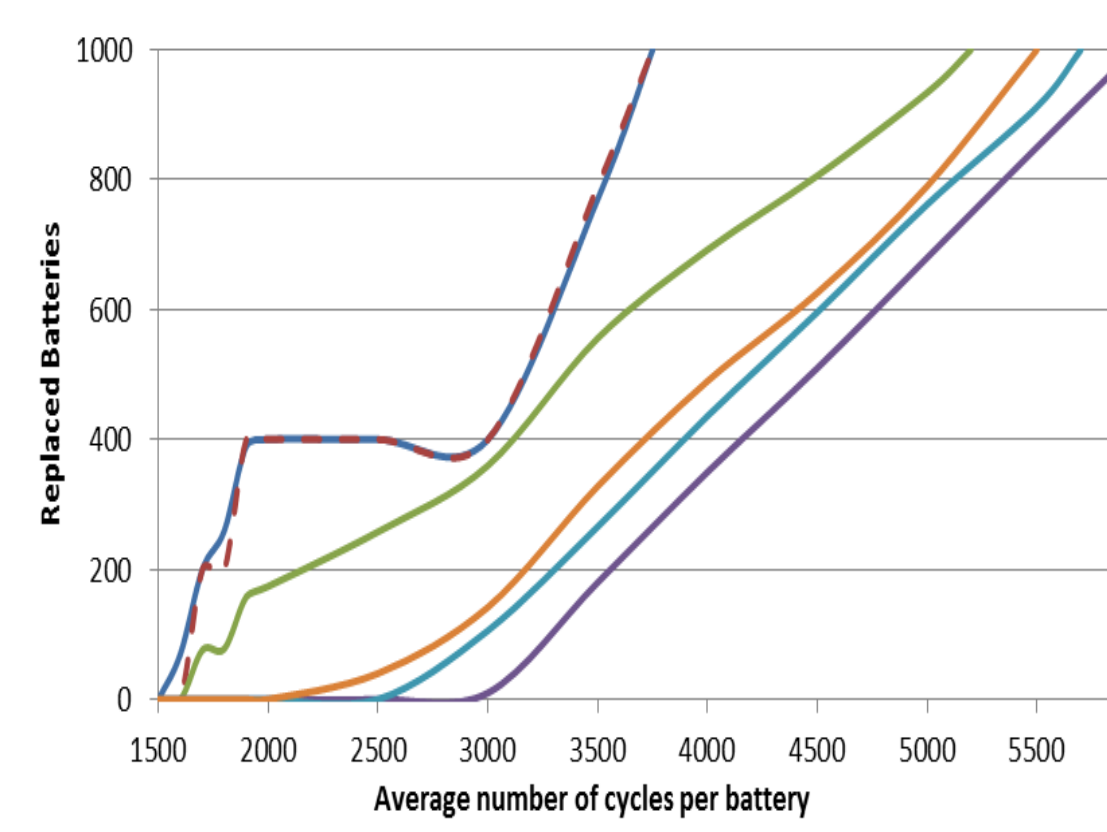
- ✓ 10x less communication overhead
- ✓ Within 6% and 3.3% of the best solution in terms of peak power shaving and average battery lifetime

Amount of energy shaved for a 10MW datacenter per week in MWhrs & (percentage of power shaved compared to the peak)

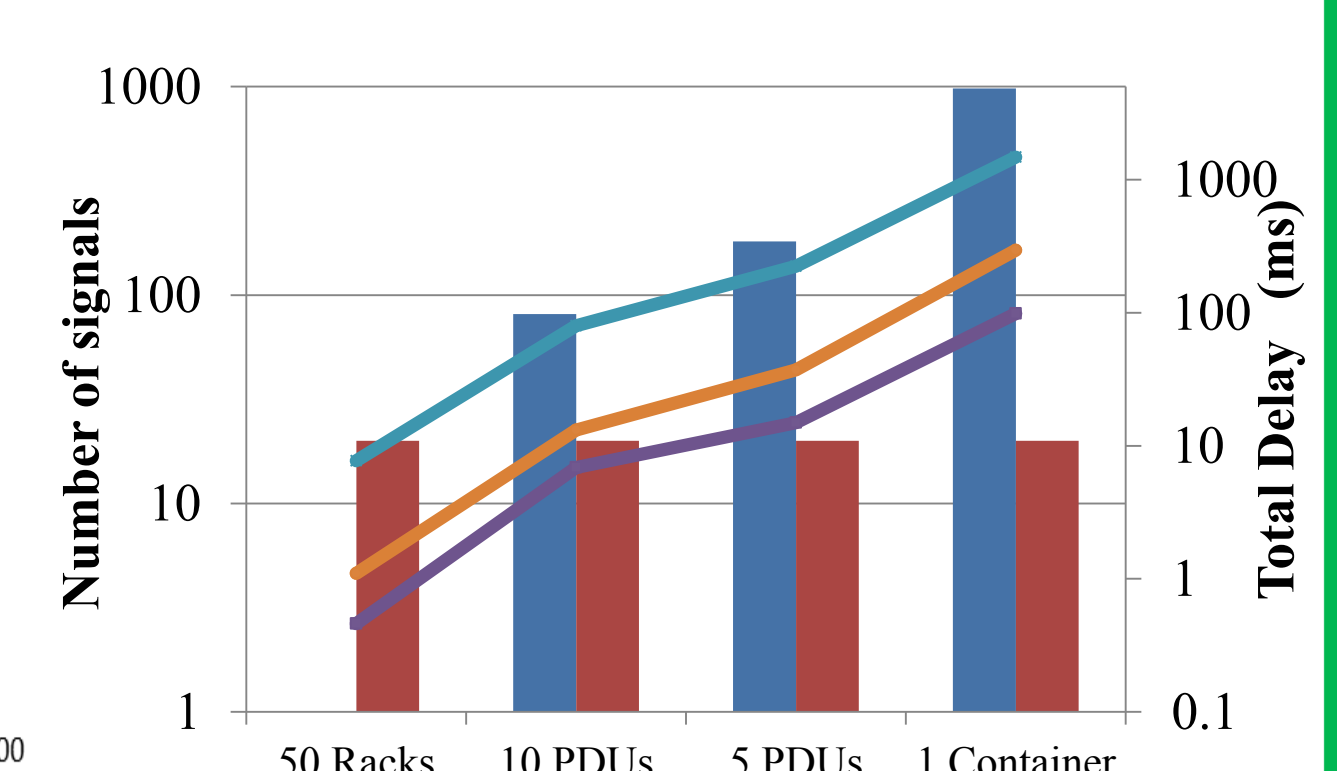
Policies	Datacenter partitioning				
	1 cont.	5 PDUs	10 PDUs	50 Racks	1000 Servers
Local	30 (19%)	14.3 (16%)	11.2 (15%)	4.8 (12%)	2.5 (10%)
Max-SoH - glob.	30 (19%)	30 (19%)	30 (19%)	30 (19%)	30 (19%)
Max-SoH - lim. comm.	30 (19%)	23.1 (18%)	14.3 (16%)	6.6 (13%)	2.5 (10%)
Max-SoH - m-lim. comm.	30 (19%)	18.1 (17%)	11.2 (15%)	4.8 (12%)	2.5 (10%)

Battery Grouping	
Hierarchy Level	Size of a group
Server	1
Rack	20-50
PDU	200
Cluster	1000
Data center	Multiple clusters

Policy	Communication
Random	Local
Round Robin	Local
Max-SoH-local	Local
Max-SoH-global	Global
Max-SoH-limited-comm.	3 groups
Max-SoH-more-limited-comm.	2 groups



Number of battery replacements with different configurations



Communication overhead analysis