Pairing Energy Storage with Solar

Tilak Gopalarathnam

LG Technology Center of America

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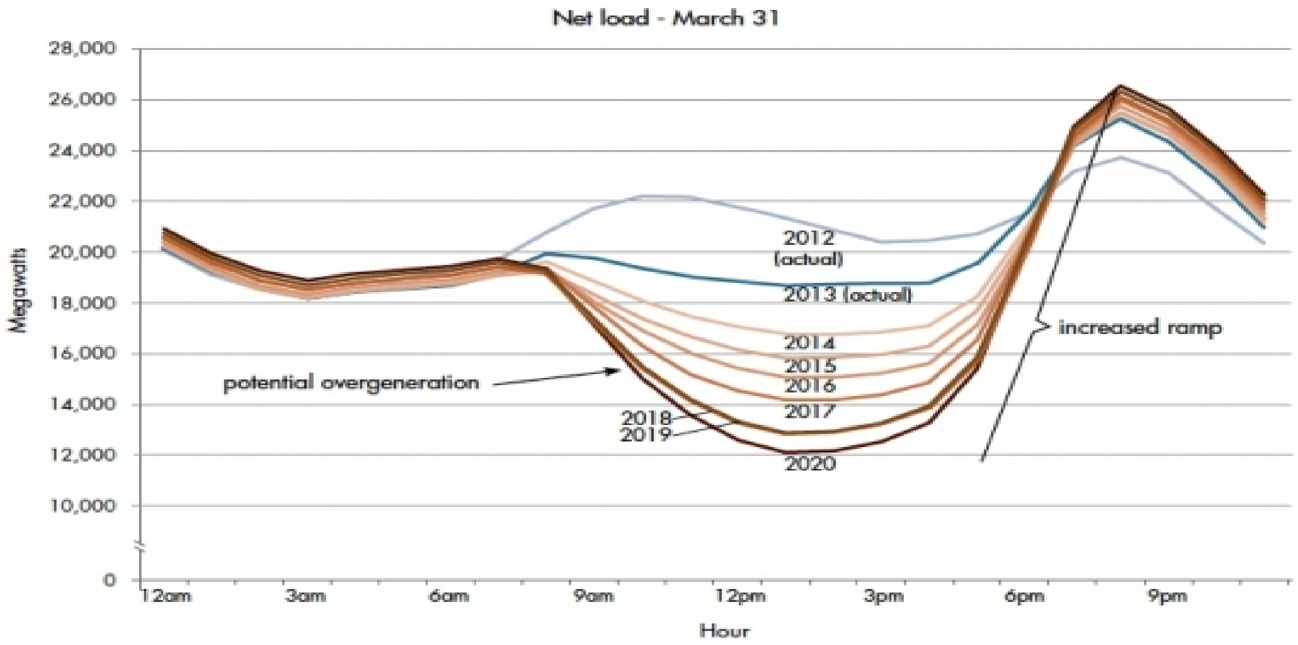
Lithium-ion battery products

The Duck Curve



Desired peaker plant output

Month/ Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HE1												
HE2												
HE3												
HE4												
HE5												
HE6												
HE7												
HE8												
HE9												
HE10												
HE11												
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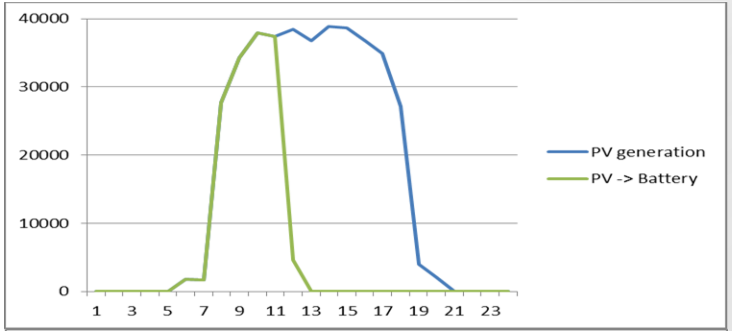
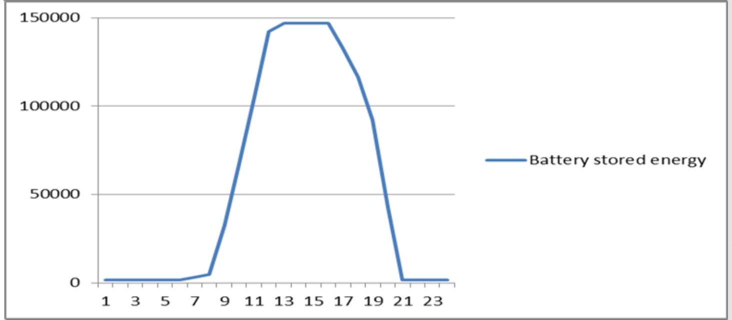
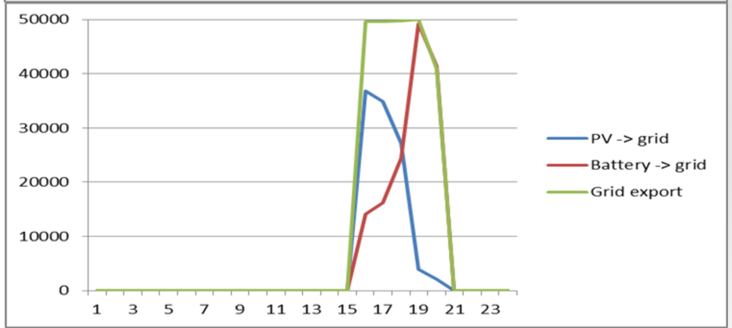
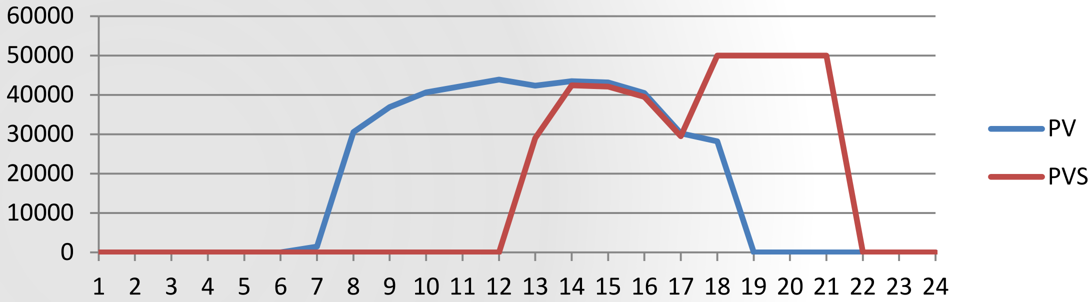
HE24												

PVS Peaker Plant Operation



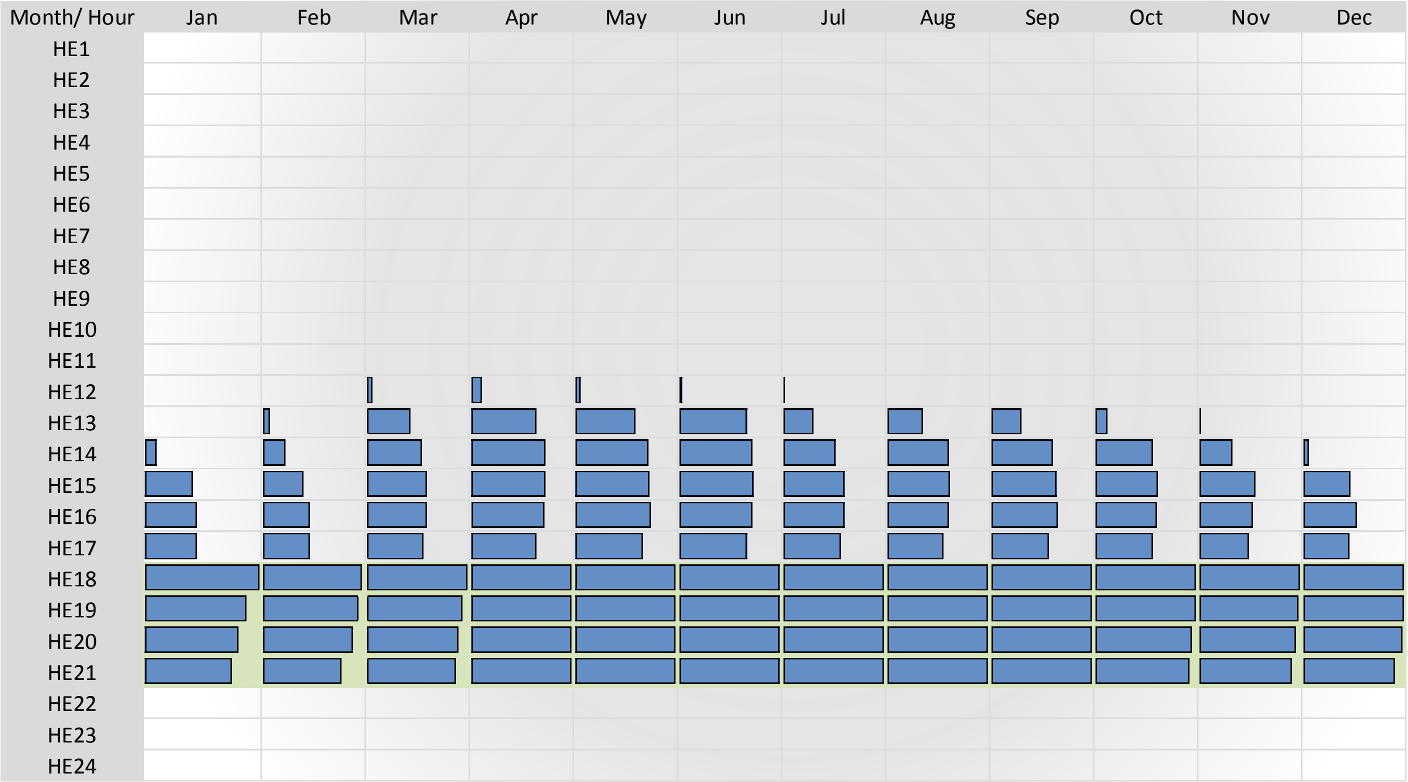






- Illustrative PVS plant
  - 50MW PV / 50MW peak period export
  - Located in the Southwestern US
  - Profiles on sunny Spring day

PV + Storage Peaker Output



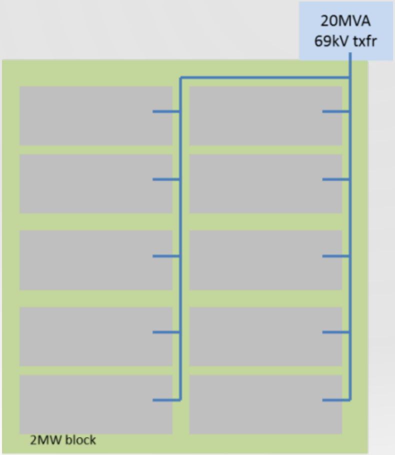
PVS Plant Architectures

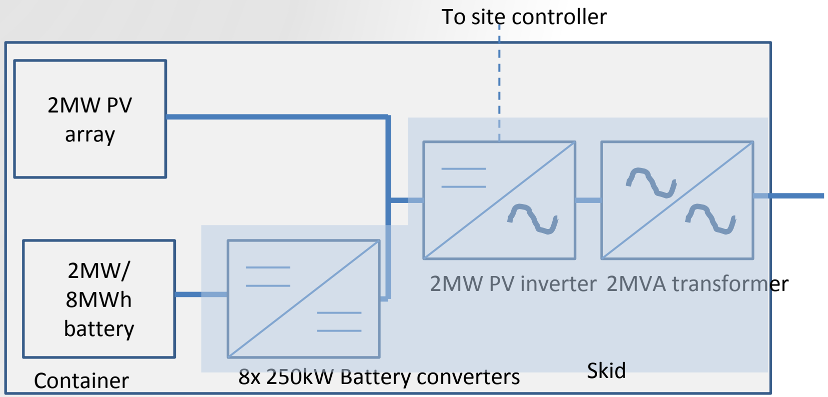
Centralized architecture

- AC coupling of solar and storage
- 50MW PVS plant layout
- 50MW PV field
- 50MW/ 150MWh ESS in a building

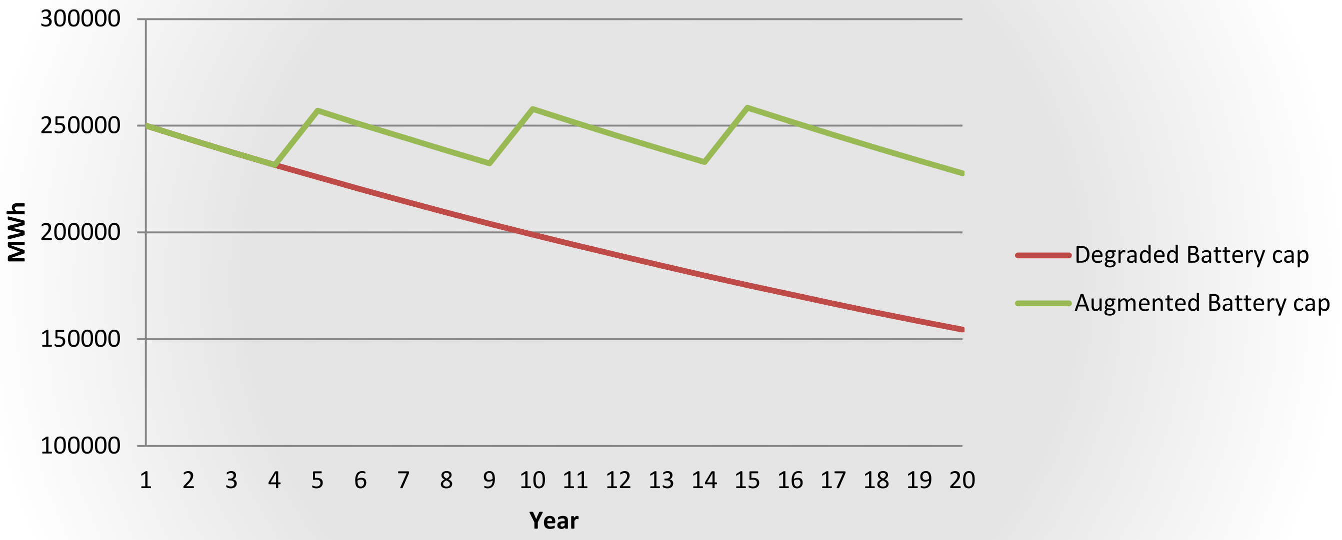
Distributed architecture

- DC coupling of solar and storage
- 20MW plant layout
- 2MW PVS blocks





Battery Augmentation



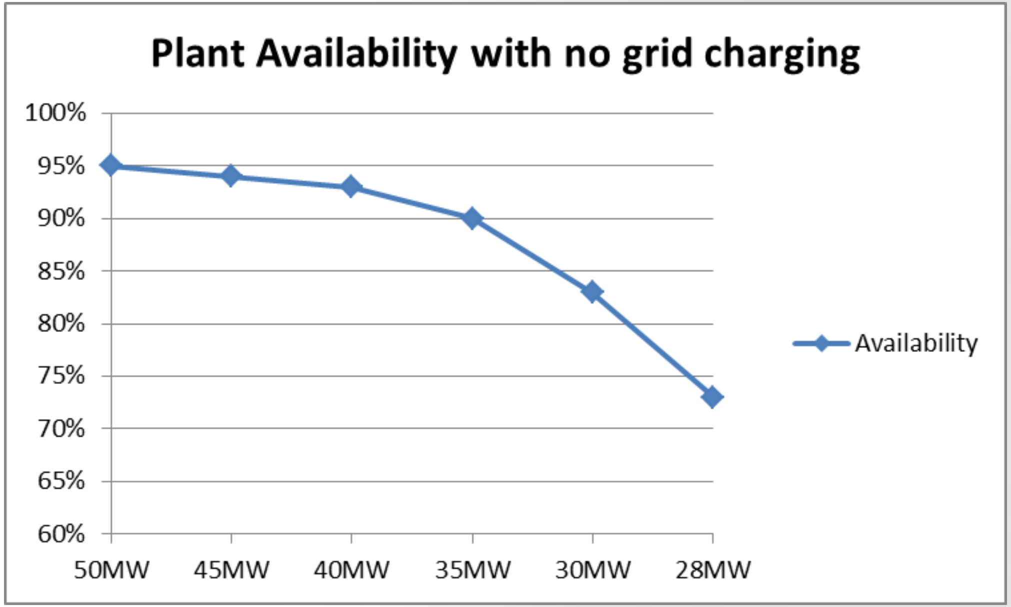
PVS plant economics

- Capex
  - PV modules, Balance of System, Batteries, Building/ container, EPC, Software, interconnection
- Opex
  - O&M, Software license, Warranty, Battery augmentation, Wholesale energy purchase
- Solar Investment Tax Credit (ITC)
  - 30% credit if construction begins before 2020, 26% if in 2020 and 22% if in 2021
  - 10% thereafter
- ITC for Storage
  - Can be applied if >75% of battery charging energy is from PV
  - Decreases linearly from 100% PV charging energy to 75% PV charging energy
- Revenue from Power Purchase Agreement
  - Rate is typically higher during peak periods (rate multiplier)
- Levelized Cost of Energy (LCOE) is used to compare economics

$$\mathrm{LCOE} = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}}$$

N: project life, 20 years
C_n: Annual project cost in year n including Capex, Opex and augmentation costs
Q_n: Energy generated by PVS system in year n, weighted by rate multiplier
d: Real discount rate

Optimizing plant size for Availability



Optimal parameters	
PV size	50MW DC
Storage size	50MW/ 250MWh
Capex	$72M
Availability	95%
LCOE	$60.07 /MWh
ITC for storage	30%

$$\text{Availability} = \frac{\text{\# of peak period hours per year with required export}}{\text{\# of peak period hours per year}}$$

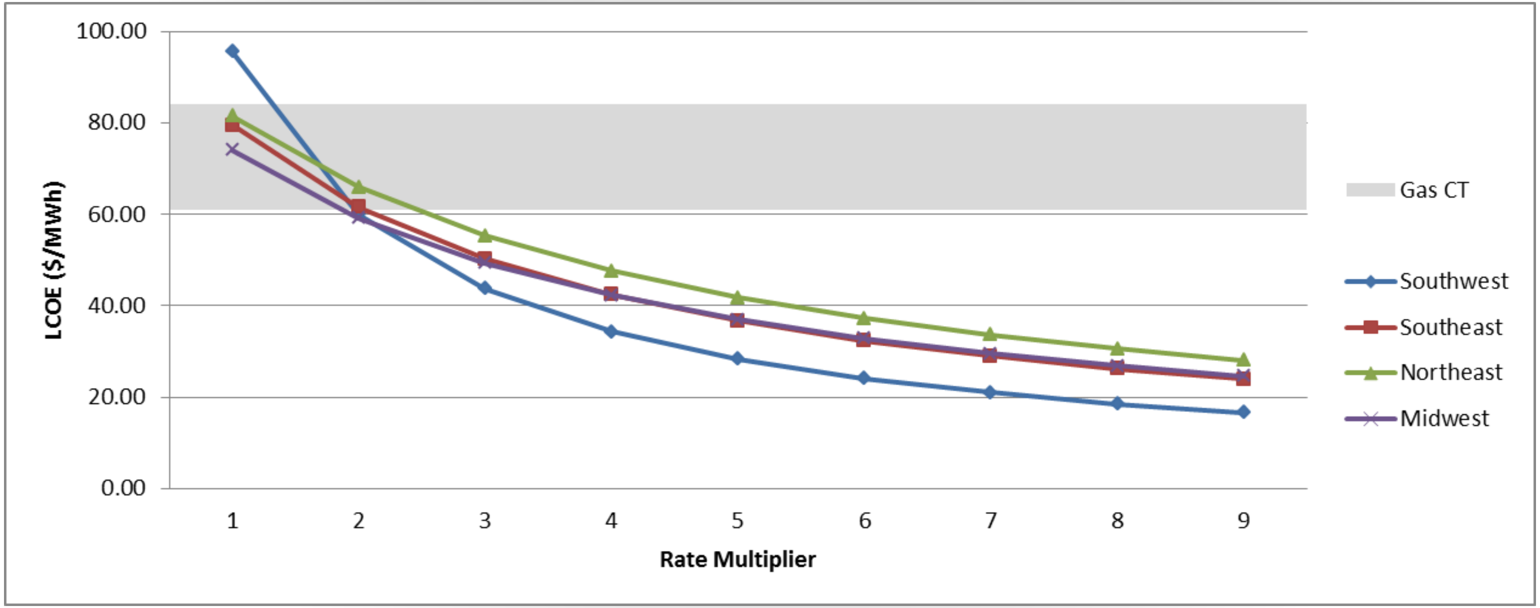
PVS plant comparison across regions

	Southwest	Southeast	Northeast	Midwest
PV size	50MW DC	100MW DC		
Min. Availability	95%			
Storage size	50MW/ 250MWh	35MW/ 175MWh	25MW/ 125MWh	30MW/ 150MWh
Storage : PV	1	0.35	0.25	0.3
LCOE (base case)	$96/MWh	$79/MWh	$82/MWh	$74/MWh

- The optimal Storage/ PV ratio of PVS Peakers varies from region to region
- PVS in the Southwest has the highest storage to PV ratio
  - High insolation with few cloudy days
  - However, base-case (flat rate structure) LCOE is highest
  - Maximizing battery size is not economical with flat rates
- PVS in the Northeast has the lowest storage to PV ratio
  - Low average insolation with many cloudy days

LCOE comparison

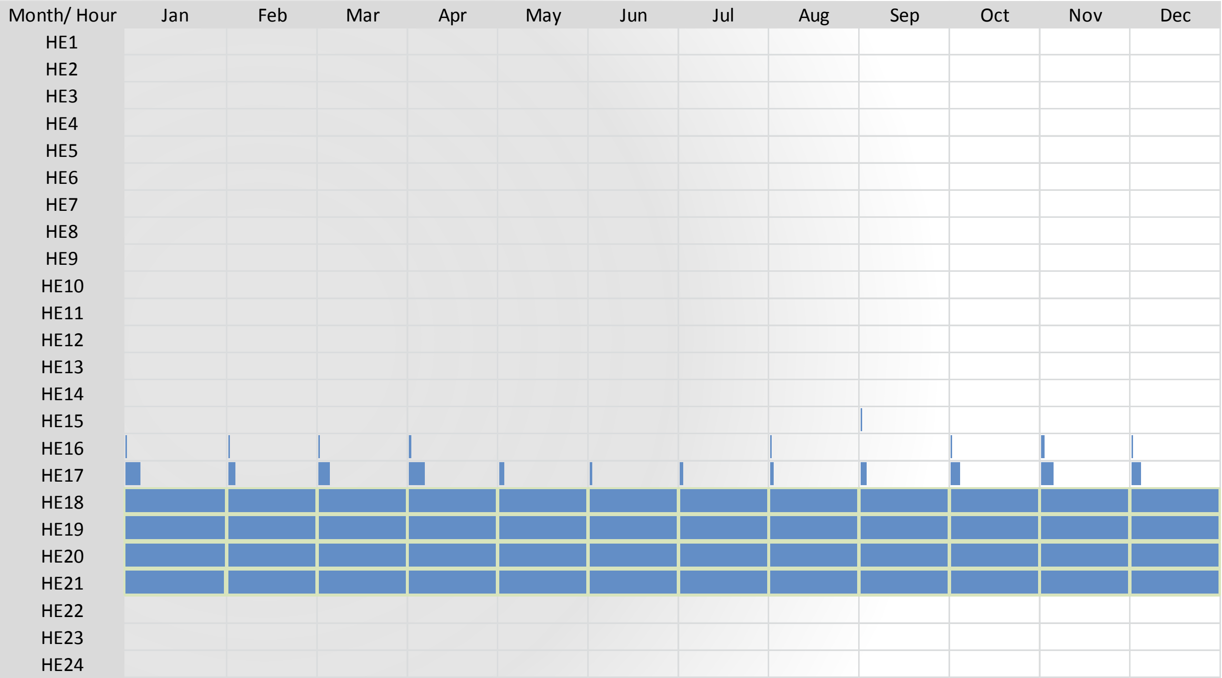
- Impact of rate multiplier
  - As the relative value of peak energy increases, LCOE of all plants decrease
  - But PVS in the Southwest shows the biggest improvement
  - For a multiplier of 3 and above, the Southwest PVS plant shows the best performance
- Competitive with Gas Combustion Turbine
  - At multiplier of 3 and above, PVS in all regions is competitive with Gas CT (2020 pricing)



$$\text{Rate Multiplier} = \frac{\text{Peak Energy Value}}{\text{Non-peak Energy Value}}$$

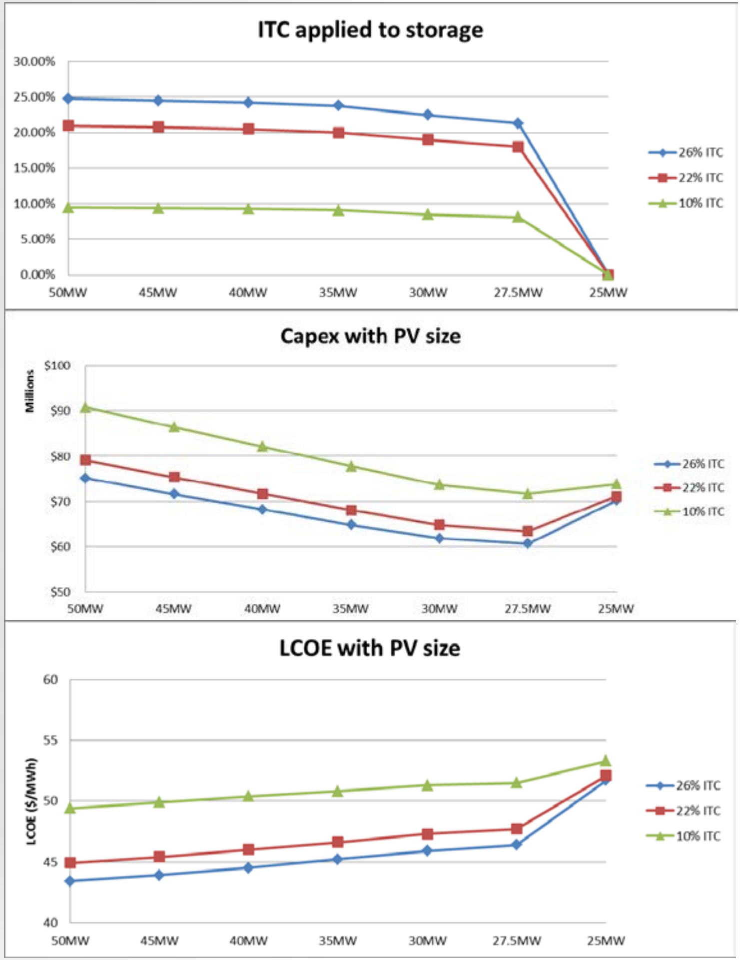
PVS with grid charging enabled

Optimal plant parameters (Grid charging)	
PV size	30MW DC
Storage size	50MW/ 240MWh
Capex	$60.2M
Availability	100%
LCOE	$45.9 /MWh
ITC for storage	26%



Optimizing charging strategy

- With partial grid charging
  - Optimal plant size is similar to the case of 30% ITC
  - Capex can be lowered by decreasing PV size
  - Lower ITC eligibility on storage



Summary

- Optimized PVS peakers are competitive with gas peakers now (with the solar ITC)
- PVS peakers should be optimized for LCOE considering both PV size and battery capacity
    - The optimal Storage/ PV ratio of PVS Peakers varies from region to region
- Distributed architecture of PVS plants can be competitive with centralized architecture even for large capacity
- Minimum required Availability will factor into PV sizing if grid charging is not initially enabled
- Lower LCOE and Capex can be obtained by enabling grid charging while increasing availability to 100%