Overview of Approaches and Emerging Practices in Interconnection of Storage and Solar + Storage

Kelsey Horowitz

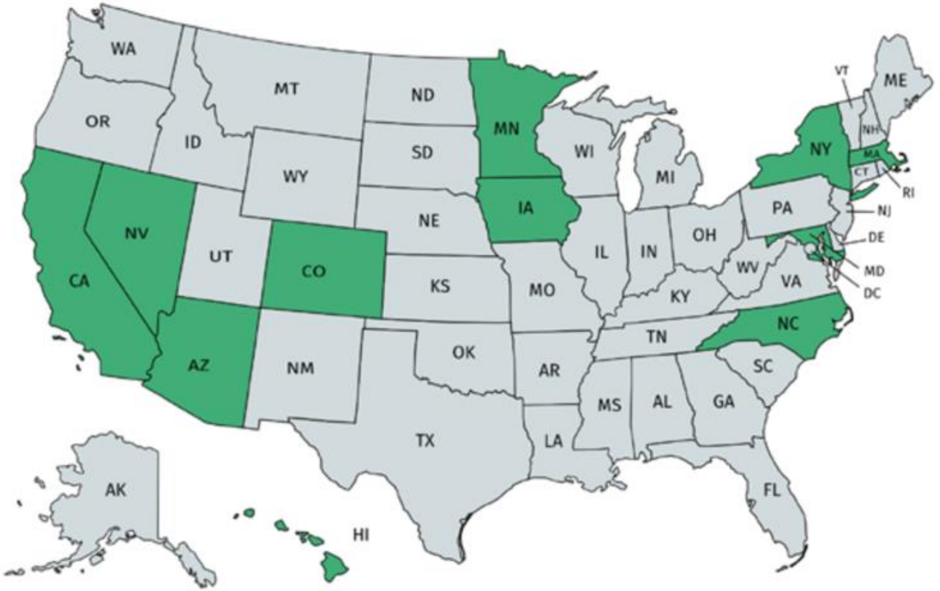
North Carolina Utilities Commission

October 7, 2019

Solar plus Storage System Configurations and Interconnection

States are in the early stages of explicitly address storage in interconnection rules

States (in green) taking steps to explicitly address energy storage in interconnection rules



North Carolina is one of the states working to address this!

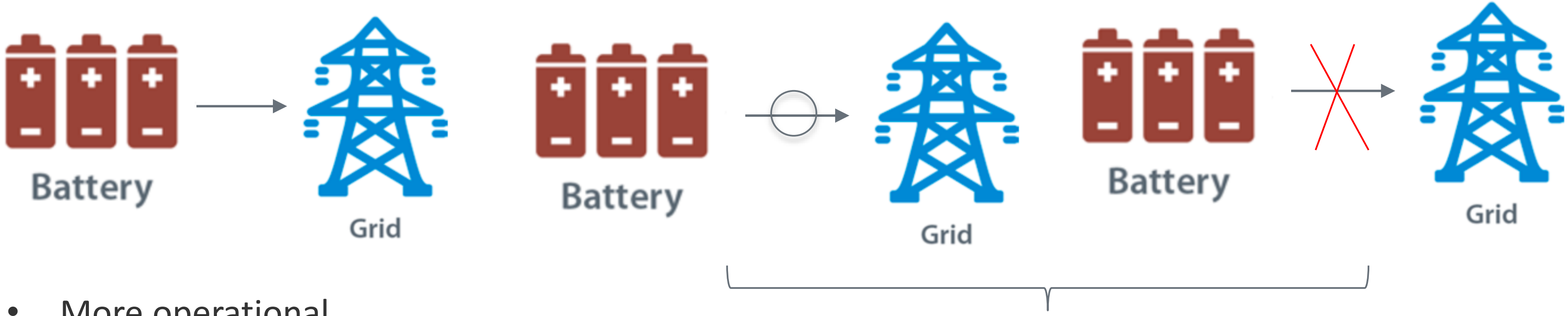
Kelsey Horowitz, Peterson, Zac, Michael Coddington, Fei Ding, Ben Sigrin, Danish Saleem, Sarah Baldwin Auck, et al. 2019. *A Guidebook for Distributed Energy Resource (DER) Interconnection*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72102. https://www.nrel.gov/docs/fy19osti/72102.pdf.

Considerations for Adapting the Interconnection Process to Storage

- Include provisions that address different energy storage configurations as well as:
  - How will the storage be used?
  - Control technologies can be used to establish appropriate parameters for use
- Address level of review each type of system will undergo

Categorizing Storage Behavior

Exporting (no limit) | **Limited export** | **Non-exporting**



- More operational flexibility for the battery owner
- Potential for larger grid impacts, which are harder to define upfront

- Tested and certified to have limited or no export
  - Nationally Recognized Testing Laboratory ("NRTL") Certified Power Control Systems and Inverters with specific requirements, or
  - mutually agreed upon tests and controls

Expedited Review Processes for Non-Exporting Storage Systems

- These systems are lower risk to the grid (if they function as intended) and have more definable behavior
- Several states have proposed or instituted expedited review processes for non-exporting storage systems
- In some cases, can forgo interconnection reviews altogether
- Non-exporting systems are not relevant for utility-scale distributed solar + storage that is not co-located with a load

California:

Non-exporting systems qualify for an expedited review if the inverter nameplate rating is ≤500 kilowatt (kW) and it meets several configuration and operational requirements

Arizona:

Considering similar rules as California

New York:

Stand-up/back-up power systems are exempt from standard interconnection requirements

Colorado:

Interconnection agreements not required for these systems

Hawaii:

Technical review not required for non-exporting, but they must be registered with the utility

Approaches Being Explored

IREC 2019 Model Interconnection Procedures

https://irecusa.org/2019/09/2019-edition-released-irecs-model-interconnection-procedures/

- "Reverse Power Protection: To ensure power is never exported across the Point of Common Coupling, a reverse power Protective Function may be provided. The default setting for this Protective Function shall be 0.1% (export) of the service transformer's rating, with a maximum 2.0 second time delay.
- Minimum Power Protection: To ensure at least a minimum amount of power is imported across the Point of Common Coupling at all times (and, therefore, that power is not exported), an under-power Protective Function may be provided. The default setting for this Protective Function shall be 5% (import) of the generating unit's total Nameplate Rating, with a maximum 2.0 second time delay.
- Relative Distributed Energy Resource Rating: This option requires the Nameplate Rating of the generating unit, minus any auxiliary load, to be so small in comparison to its host facility's minimum load that the use of additional Protective Functions is not required to ensure that power will not be exported to the Electric Delivery System. This option requires the generating unit capacity to be no greater than 50% of the Interconnection Customer's verifiable minimum Host Load over the past 12 months.
- Configured Power Rating: A reduced output rating utilizing the power rating configuration setting may be used to ensure the DER does not generate power beyond a certain value lower than the Nameplate Rating"

Inadvertent Export

- Allow up to 30 seconds of maximum export for any single event
- Total inadvertent exports must remain within an acceptable kWh limit
  - Utility may monitor to verify
- Fail safes: system will enter a specific, safe, pre-defined mode if controls system failures occur
- Not fully addressed in IEEE 1547-2018
  - State standards address instead
  - Emerging UL testing procedures and standards

Limited Export in Retrofit Solar + Storage Systems

Photovoltaics

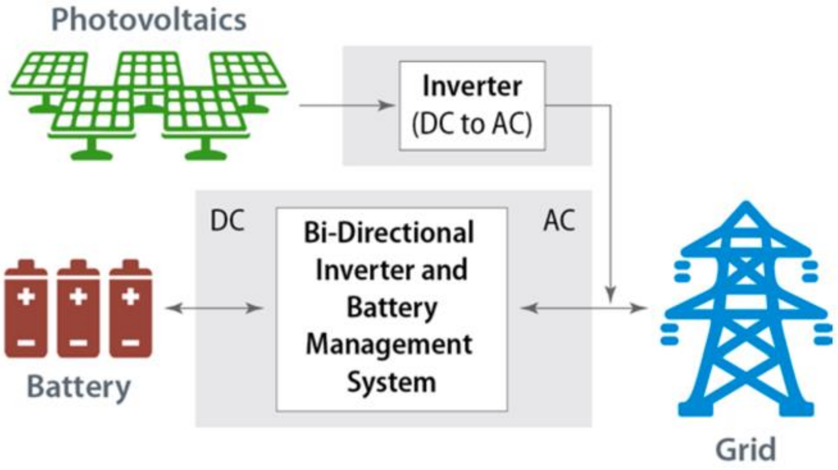
Battery

- Limited export levels could be set to keep export at a level to be the same as the nameplate PV system export used in the original interconnection study
  - Or at a level otherwise known to be acceptable at that portion of the grid

Adding Storage to a Site

- Rather than requiring a new interconnection application, some utilities are experimenting with asking for system changes instead through an iterative process
  - Although this practice benefits all technology types, it is particularly relevant for storage systems, which are highly controllable.

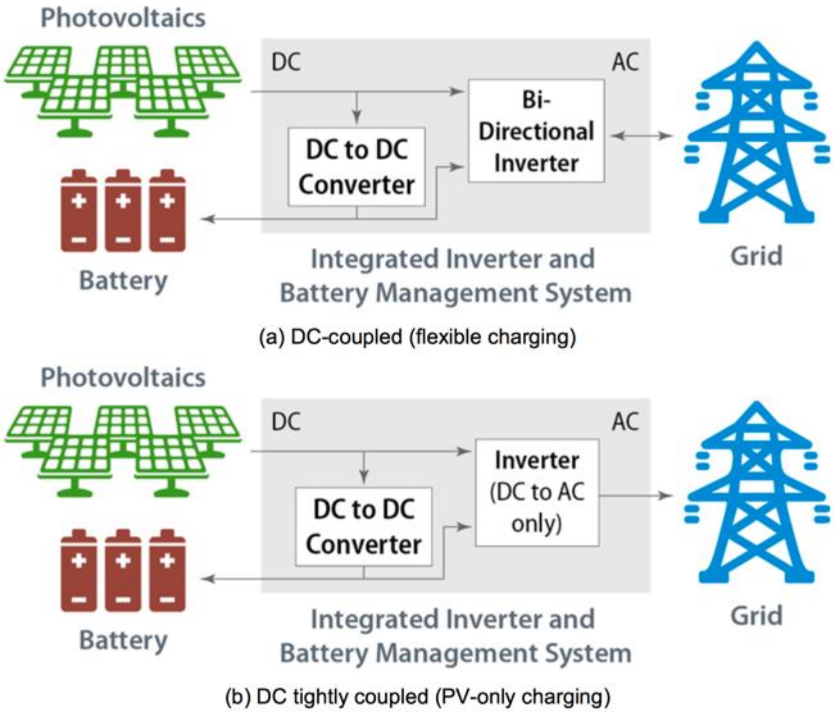
How Much Can Solar + Storage Systems Export Under Different Configurations?



- Retrofit systems may be **AC-coupled**, since that would not require replacing the existing inverter
- In this configuration, the battery is physically capable of charging from and exporting to the grid directly
  - But controls and requirements could be put in place to limit
- The maximum physical output of the battery plus the solar system could potentially be the full battery and solar capacity (**AC**)
- However, in practice, max output would be:
  - Battery operating or usable capacity (limited by battery control software)
  - Solar output different from its rated value, consistent with the maximum irradiance in a given location

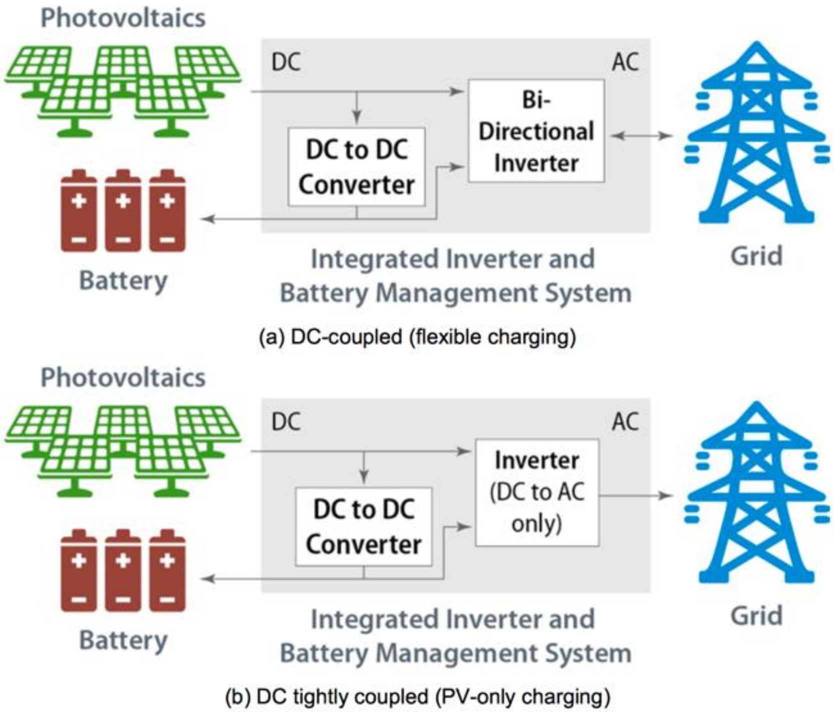
How Much Can Solar + Storage Systems Export Under Different Configurations?

- In DC coupled systems, the output (and capacity value) is limited to the AC inverter rating
- In the tightly DC coupled case, storage only charges from the PV and so cannot act as an additional load



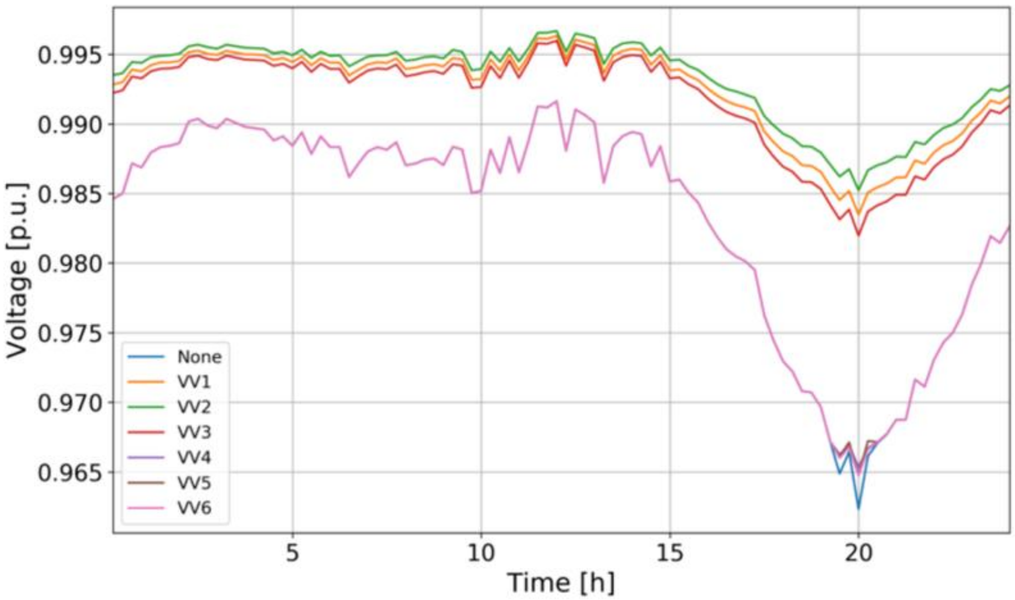
Retrofitting Existing Solar Sites with DC Coupled Storage

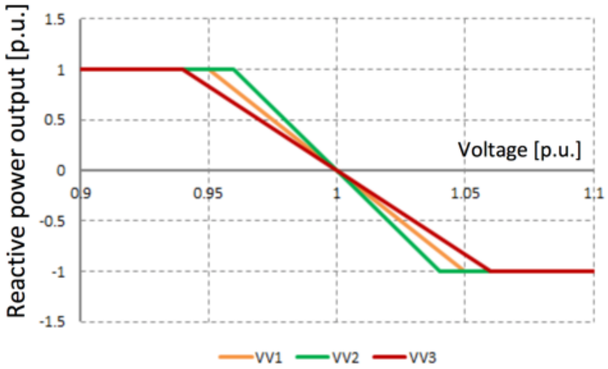
- Could require replacing the existing solar inverter
  - May not if the original solar system was designed to be "storage ready" facility (inverter, controller, etc.)
- Solar inverters do not last as long as the panels, and will likely need to be replaced at some point for old plants
- If the existing inverters are legacy inverters, new inverters could be installed that have advanced features and area aligned with the new IEEE 154-2018 standard
  - These could provide additional grid support

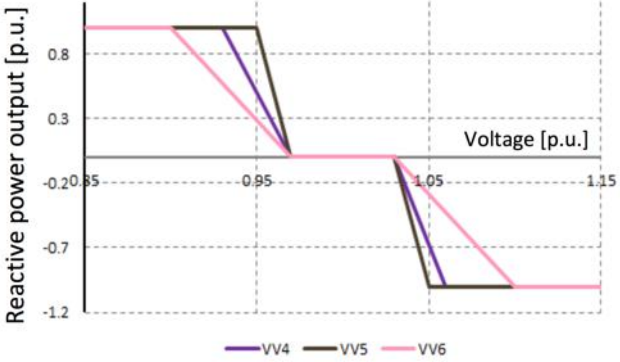


Example of Storage Providing Voltage Support

- Results depend significantly on the control mode used!
- Valuable to test and confirm that battery operates in expected control mode







Potential Impacts of Storage on the Distribution System

Storage Impacts on the Distribution System

- These impacts are very feeder specific, and depend on:
  - Storage location and operating/control modes
  - Load
  - Grid controls and existing state of the grid
  - PV and other DER location and penetration, and their controls/operations

Potential Effects of Storage on the Distribution Grid

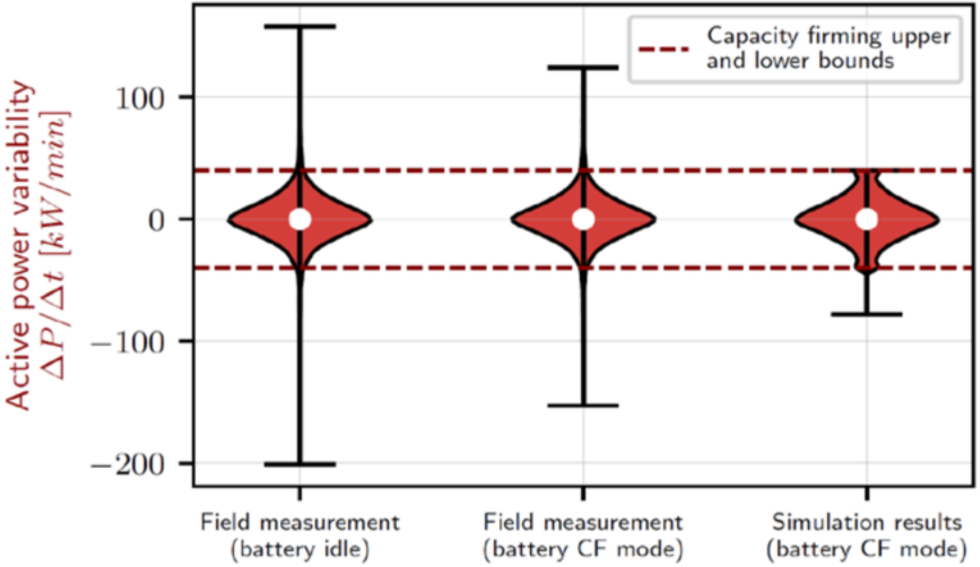
Capacity Firming

- Substation Capacity Firming Can reduce the number of LTC operations required at the substation level, possibly resulting in a reduction of operation and maintenance (O&M) costs
  - with or without PV
- Renewables Capacity Firming: Firm variable generation output and firm PV output during critical load periods
  - On distribution system, this could also potentially reduce device operations and O&M

Voltage and Thermal Loading

- Storage can help reduce voltage and thermal loading, with or without PV present
  - Expanding hosting capacity
- It can also negatively impact voltages and loading, depending on how and when it is operated:
  - Discharging: could create high voltages or overloading A
    - If limited by inverter capacity, would not be higher than what was anticipated with PV alone
  - Charging: could create low voltages or or overloading

Example of Capacity Firming: Modeled and Field Measurement



- Validation of models of impact and value is important
- Often, distribution networks don't have good visibility or monitoring, which can make this challenging in the field

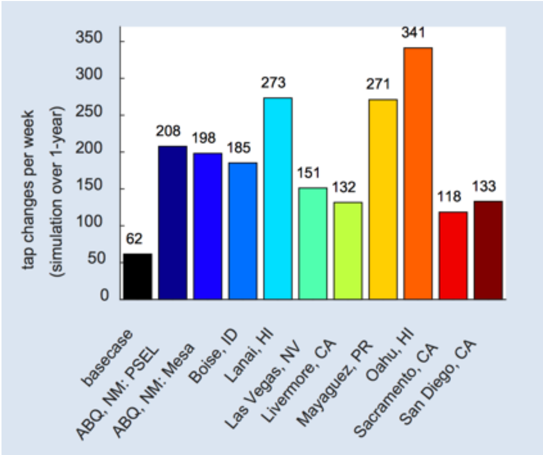
Potential Effects of Storage on the Distribution Grid

- Limit reverse power flow from PV and other distributed generation at the substation
  - Can also expand hosting capacity, since some utilities treat this as a limit on interconnection
- Reduce loading on the distribution feeders and substations
  - Substation upgrades are expensive
- Regulate voltage on the feeder
  - Depends on the inverter used, controls/operational modes, and placement

Firming and O&M Associated with Distribution Device Operations

- Varies a lot by feeder, location, type & placement of devices
- Costs may be minimal (e.g. to replace a capacitor switch) or high (e.g. if whole LTC transformer must be replaced)

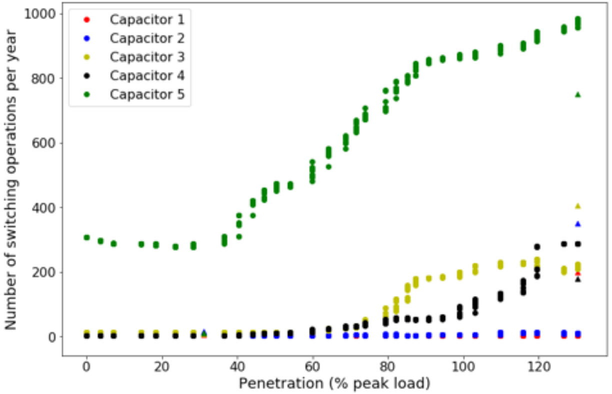
Examples of LTC Weekly Operations with PV in Different Locations

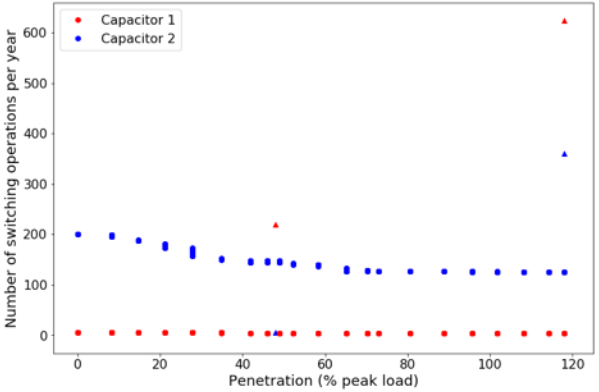


- 17,732/year in Oahu with PV (compared to 3,224 without)
- 100,000 operation lifetime

Other factors besides operations (e.g. environmental factors) also influence lifetime and O&M

Number of capacitor switch operations with different PV penetration levels without storage on two different feeders





OFFICIAL COPY

Oct 18 2019

Firming and O&M Associated with Distribution Device Operations

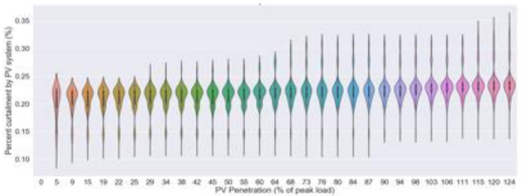
- NREL study in found negligible impact on O&M costs deploying storage and optimizing its dispatch, but this will not always be the case

Components	TEST FEEDER
Feeder length	8 miles
Peak load	6.2 MW
Capacitor banks	3
PV generation	2.5 MW
Node count	2,500

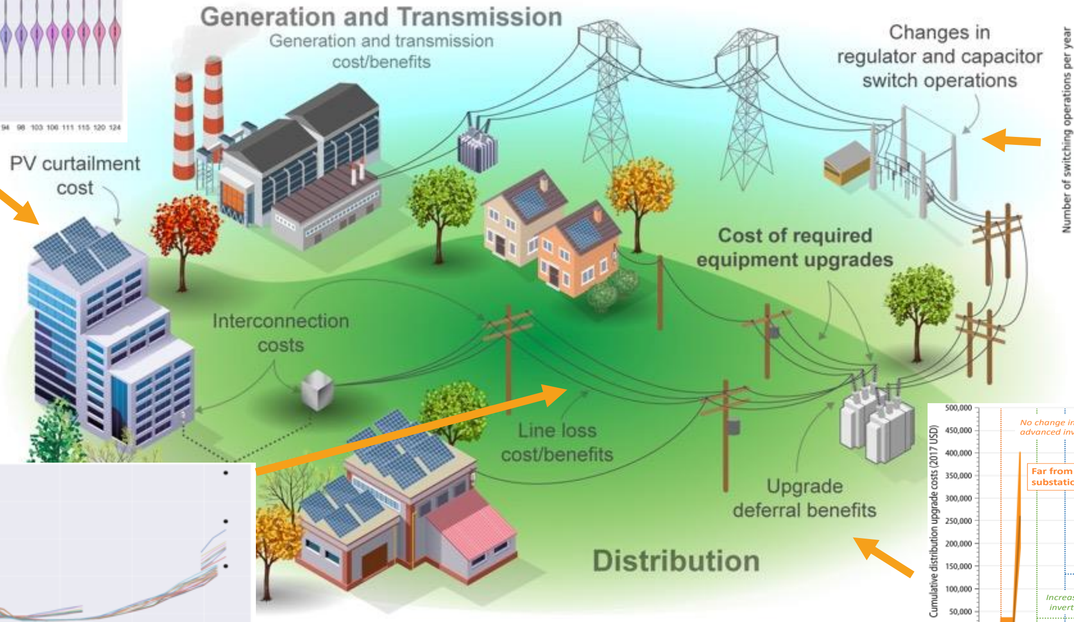
Table ES-2. Summary of the Value Streams Analyzed Along with Key Optimal Dispatch Results

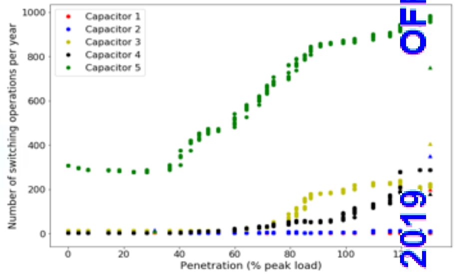
Value Stream	Monetization Mechanism	Year 1 Savings	Life-Cycle Savings
Peak shaving	Transformer upgrade deferral	–	$121,135
Capacity firming	Operation and maintenance savings from reduced LTC operations	–	–
Voltage support	New capacitor bank deferral	–	$7,463
Energy arbitrage	Time-shifting energy purchases on the LMP market	$56,069	$837,115
Total			$965,713

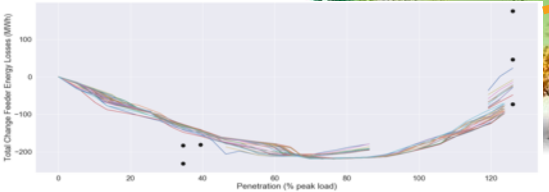
Holistic Techno-Economic Analysis

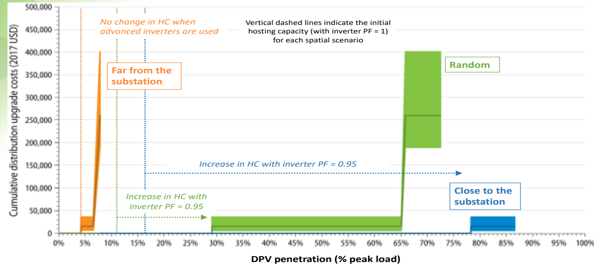


+ Replicability
&
Validation









Additional Considerations for Storage Interconnection

- Storage can trigger the same upgrade based on both charging (load) and discharging (generation) modes
  - Cost allocation may be different for load versus generation upgrades
  - Cost allocation rules for storage should be clarified in interconnection policies
- Storage behavior is complicated, and the distribution system impacts can be complex to model
  - Providing transparent screen and study results can improve help move the process forward
  - Sometimes simple system modifications may be made to the site to address technical concerns, and there could be an iterative process if clarified

Assessing the Impacts of Storage

Determining the size of storage and its operational characteristics is key for analysis

Battery Capacity and Potential Output

- Nameplate or nominal capacity: Ah the battery is theoretically able to store based on the coulometric capacity
- Nameplate or nominal energy: Wh rating, calculated similarly to the capacity
- Not good metrics for interconnection review if you have a non-exporting or export-limiting system

- Usable capacity or operational capacity: kWh the battery is able to store based on limits on depth of discharge, efficiency, and charge/discharge rate restrictions to ensure the battery life and integrity is not significantly effected
  - Some batteries are "high durability," with longer life at the expense of limits on energy and capacity

- Storage may not export at its nameplate capacity, and will export at its kW rating for limited durations of time

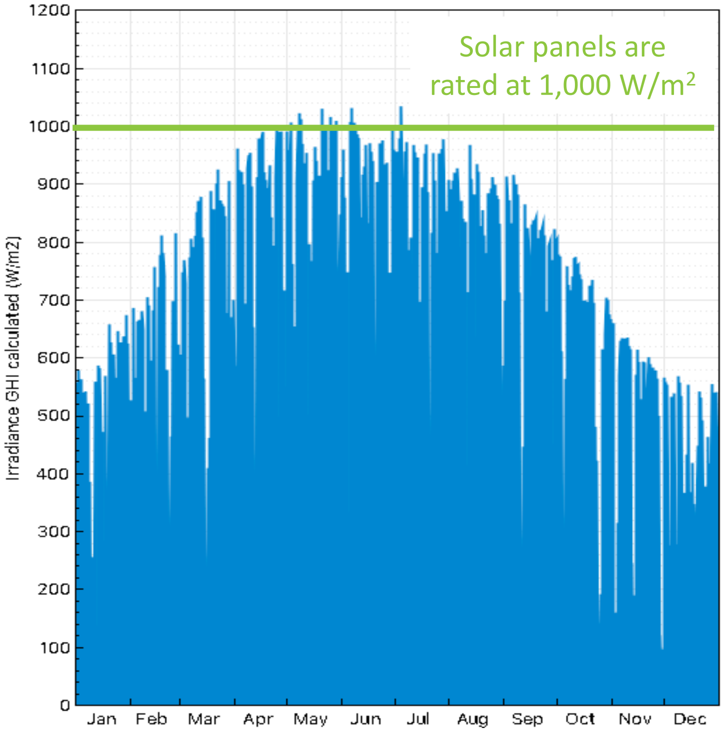
  → Potential for time-series analysis and probabilistic screens

Solar Output

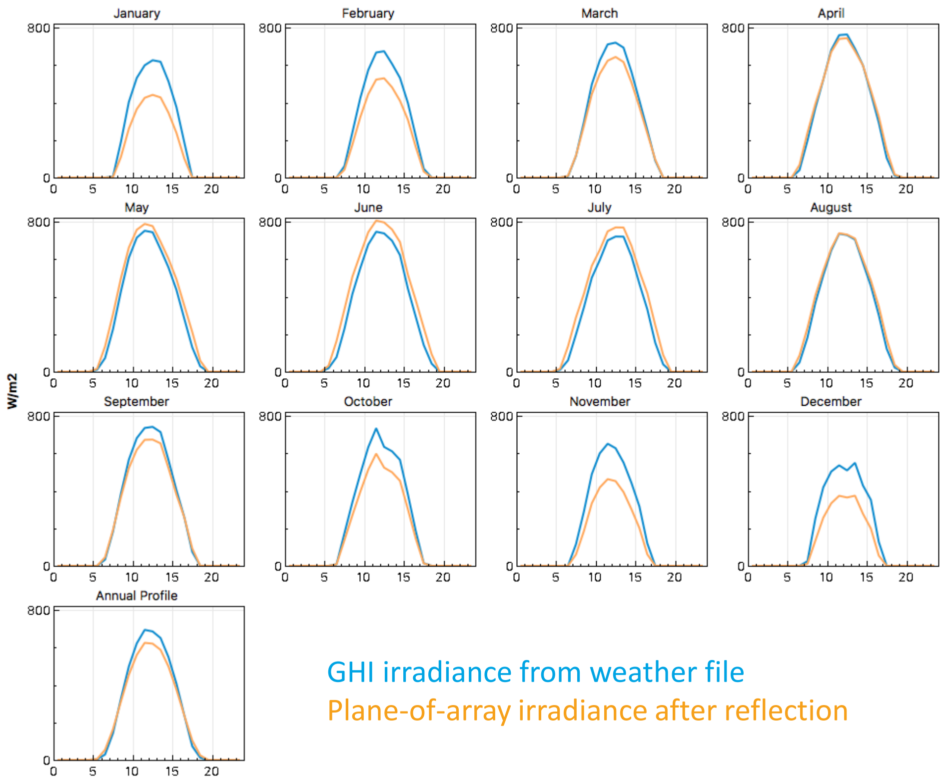
Example shown for Raleigh, NC based on TMY weather data in SAM

On average, irradiance is < 80% of 1,000 W/m², with even less getting to the panel

Hourly irradiance



Average Daily Irradiance Profiles



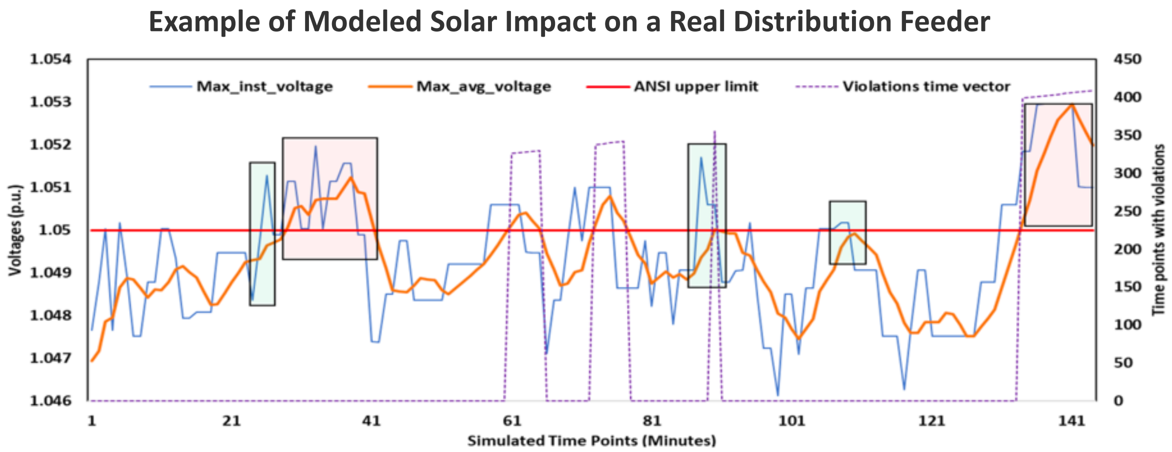
GHI irradiance from weather file

Plane-of-array irradiance after reflection

OFFICIAL COPY

Oct 18 2019

Dynamic Hosting Capacity/Probabilistic Screening

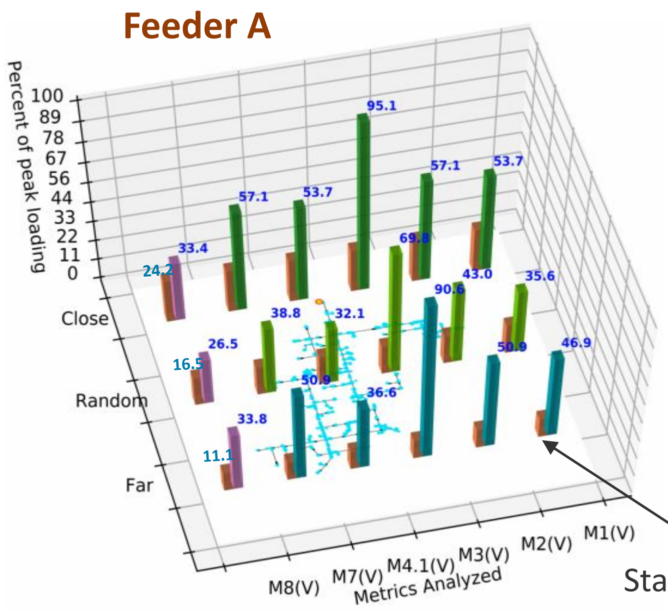


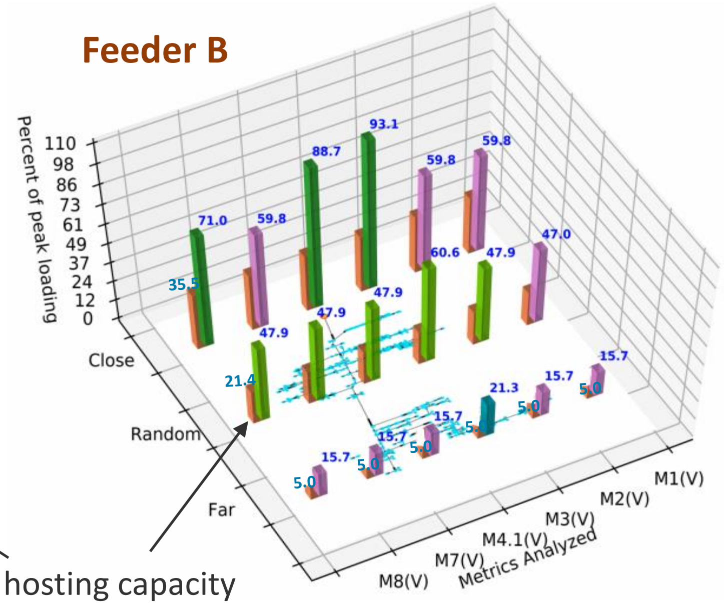
Jain, Akshay Kumar, Kelsey Horowitz, Fei DIng, Nicolas Gensollen, Barry Mather, and Bryan Palmintier. "Quasi-Static Time-Series PV Hosting Capacity Methodology and Metrics," 2019.

- High periods of solar and/or storage output could cause:
  - High voltages
  - Overloading of lines and transformers
- Periods where storage is acting as a large load could cause:
  - Low voltages
  - Overloading of lines and transformers
- BUT these violations could occur for only a limited duration, and with a limited severity that does not cause problems with the reliability of the grid or lifetime of equipment

Probabilistic Screening Analysis

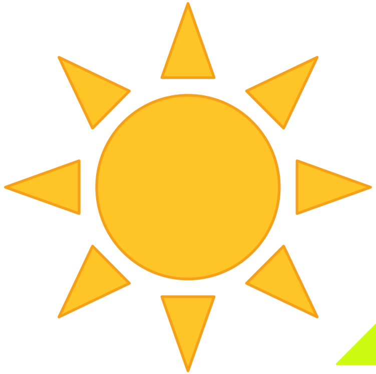
- Using dynamic hosting capacity analysis could enable 10% to 25% more PV capacity (200 kW to 1.84 MW) at no (or very little) cost
- Ongoing efforts to apply probabilistic analysis and develop risk frameworks for storage as well, both for interconnection and siting





Static hosting capacity = orange bars

How much solar or solar + storage can the electric power system host?



Source: U.S. DOE

HC = hosting capacity

Static HC
- Fit & forget
- Worst case static snapshots

Uncoordinated Dynamic HC
- Local autonomous control
- w/o communications
- Probabilistic screens

Coordinated Dynamic HC
- Communications based
- Resolve multiple DER and multiple constraints
- Revenue less predictable, depending on contract structure

https://www.nrel.gov/solar/advanced-hosting-capacity-analysis.html

Challenges Associated with These Analyses

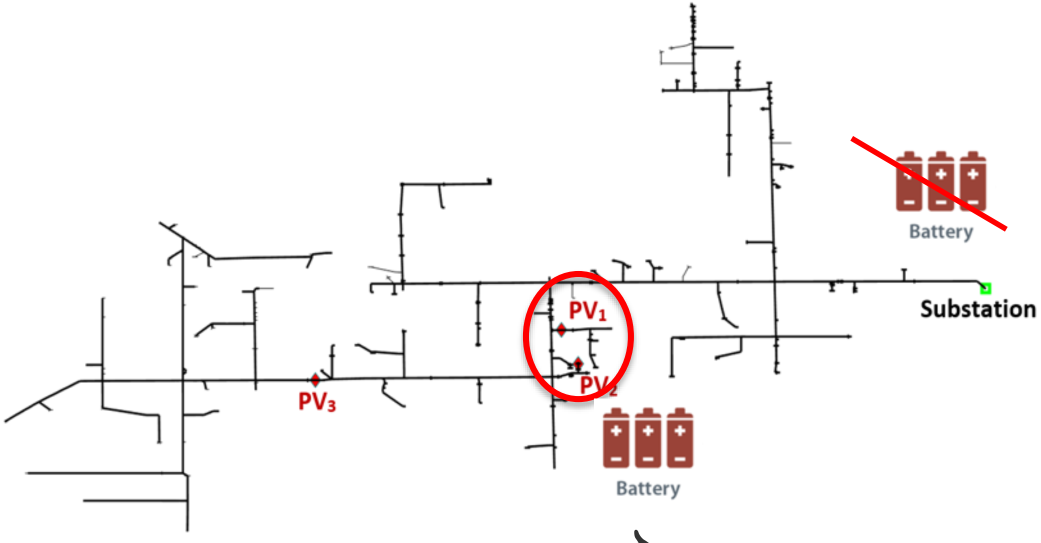
- For many scenarios, computation time can be burdensome
  - But limited number of scenarios are feasible for computation on laptops
  - Fast quasi-static time-series (QSTS) analysis methods have also been developed: 83.9% reduction in computational time with no appreciable error
- Data availability and quality is ultimately what can limit this type of analysis
  - Ongoing work on the sensitivity of errors in estimating distribution system impact to missing data or data resolution

https://www.nrel.gov/docs/fy17osti/67769.pdf

Co-Located Solar and Storage Considerations

Co-located Solar and Storage

- Co-located solar and storage (as opposed to spatially separated) can also provide mitigation of local overloading caused by the solar plant during high output, e.g. on secondary networks and distribution transformers



Co-located Solar and Storage

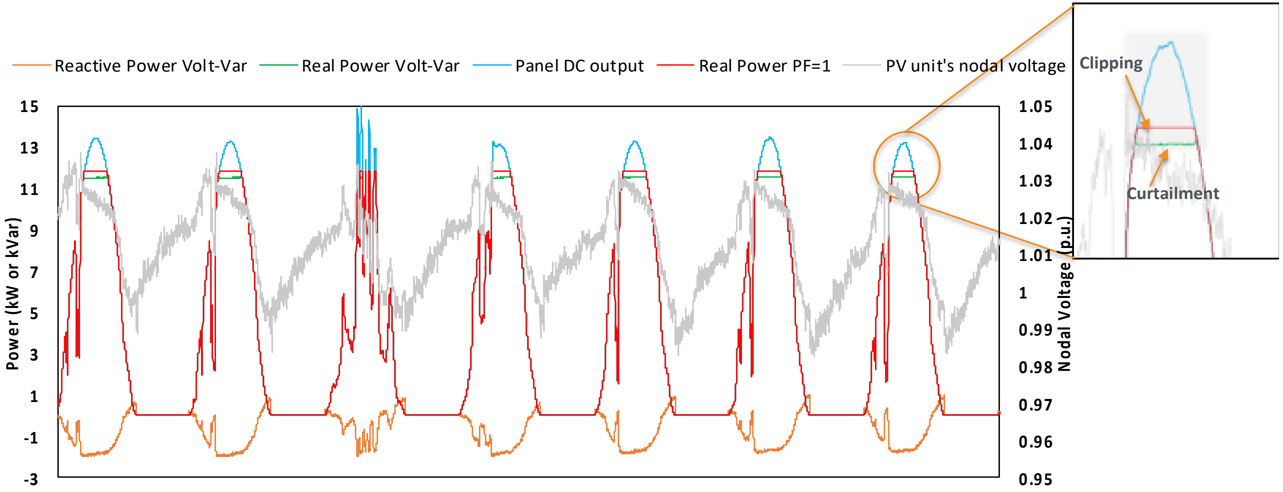
- However, if there are no local overloads triggered by the PV and multiple PV systems are on one circuit, adding storage at another location on the grid *could* help mitigate issues and result in a total lower cost if allocated among the PV generation capacity
  - e.g. capacity firming for bulk system needs
- Prior analyses on placement of storage with PV present have shown the optimal is not always at the location of PV systems

Co-located Solar and Storage

- Adding the battery energy management system or new inverter to the solar site could improve voltage regulation capability if the existing inverter didn't have advanced features
- Installing at the time of inverter replacement could be an opportunity for cost savings and upgrading the inverter to align with new standards

Co-located Solar and Storage

- Provides an opportunity for storage energy that would otherwise be clipped or curtailed
  - However, storage costs are almost always much higher (today) than the cost of lost revenue from clipping and/or curtailment
  - This could change in the future with lower storage costs and high curtailment levels with high penetrations of solar



Co-located versus Separate Solar and Storage Costs

Fu, Ran, Timothy Remo, and Robert Margolis. 2018. *2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71714. https://www.nrel.gov/docs/fy19osti/71714.pdf.

- Lower balance-of-system costs
    - Degree of cost reduction depends on the configuration and if installed together initially or retrofit

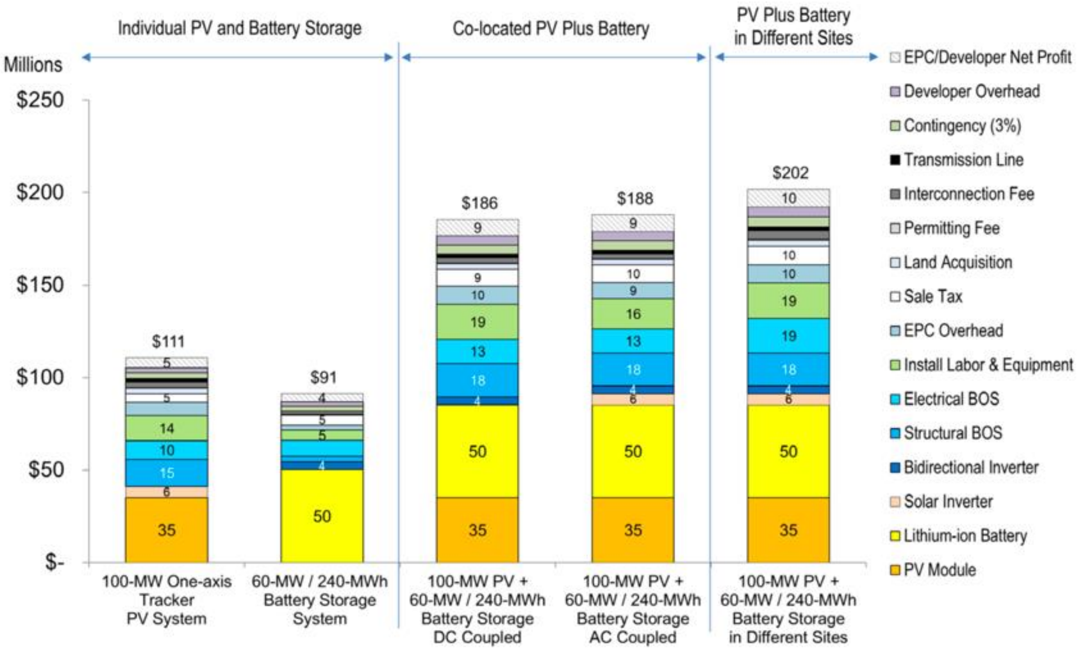
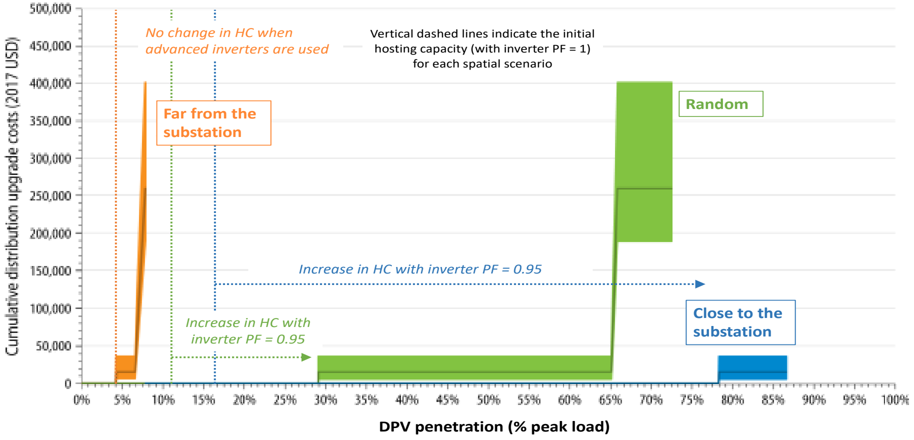


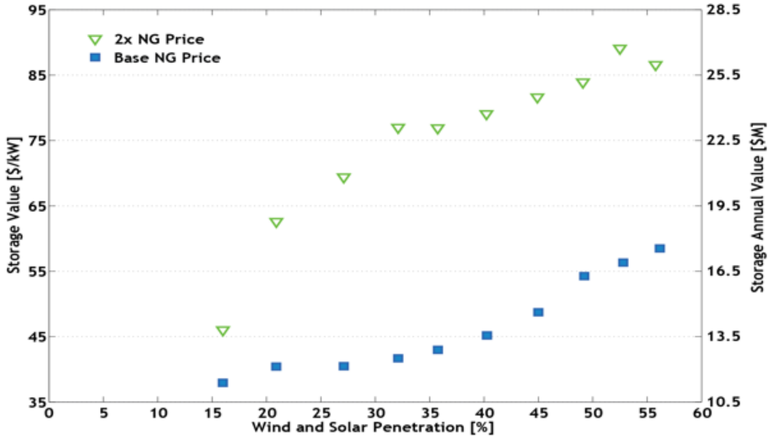
Figure ES-2. 2018 Cost benchmarks for PV-plus-storage systems (4-hour duration) in different sites and the same site (DC-coupled and AC-coupled cases)

Community Energy Storage

- Could also provide services described above, as well as back-up power during outages
- May be deployed standalone or with solar

Change in Storage Value as a Function of Variable Renewable Energy Penetration

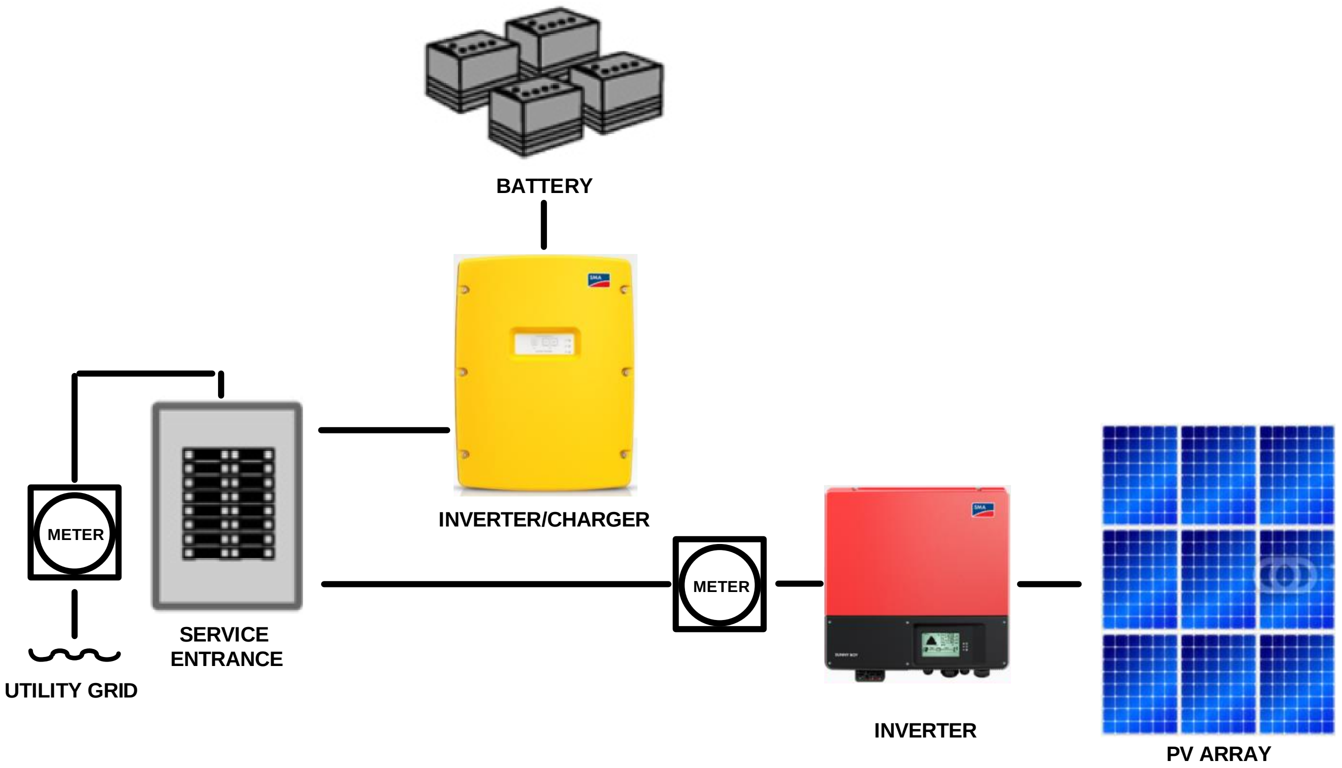




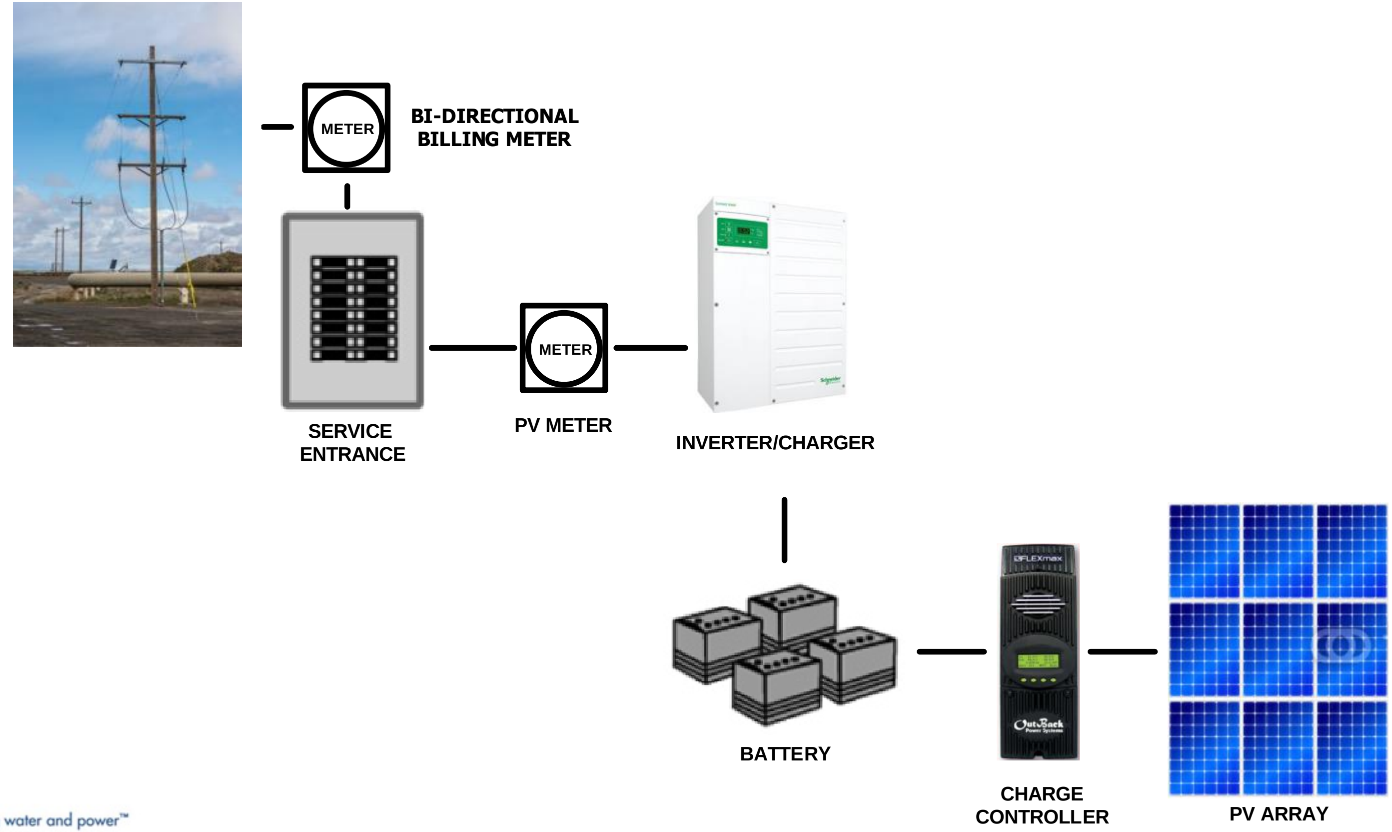
- As solar deployment increases, both distribution system and bulk system value of storage increases
- Economics still only make sense in some scenarios at these penetrations, but prices are dropping
- But having more storage on the grid with solar can facilitate solar integration without requiring additional system infrastructure upgrades, **depending**

Metering Co-Located Solar and Storage

Grid-tied Solar with Storage: AC Coupled no Backup with PV

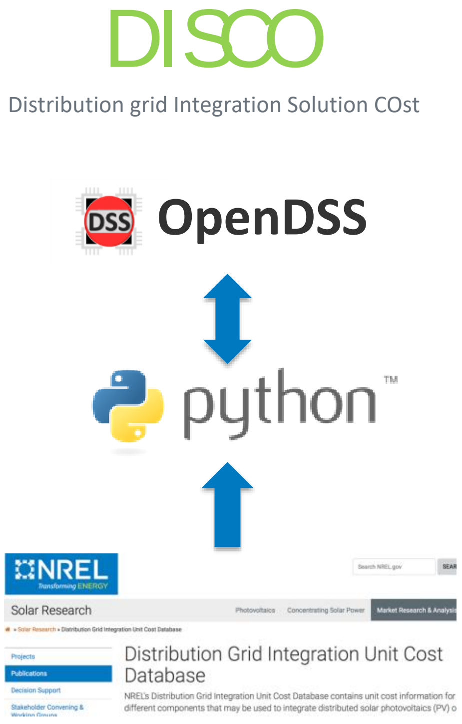


Grid-tied Solar with Storage: DC Coupled no Backup with PV



NREL Tools and Data

- NREL Distribution Grid Integration Unit Cost Database:
  https://www.nrel.gov/solar/distribution-grid-integration-unit-cost-database.html
- DISCO = Distribution Integration Solution Cost Options
  - Not yet publicly available, but would like to create a version for release eventually
- Solar and storage modeling tools:
  https://www.nrel.gov/docs/fy18osti/71146.pdf
  https://www.nrel.gov/docs/fy19osti/71804.pdf
- Test facilities for storage:
  - ESIF
  - Flatiron Campus
- Publications on interconnection as well as storage and storage grid integration analysis, solar + storage issues:
  https://www.nrel.gov/research/publications.html



supplemented with industry interviews to collect additional cost data

Thank you! Q&A

www.nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL
Transforming ENERGY