**A Guide to This Database**

**READ ME**

The goal of the database is to provide a useful, curated, and transparent source of information for assessing distribution grid integration costs associated with PV. It includes information on traditional system upgrades that could be used to mitigate any impacts, as well as additional information on costs associated with advanced solutions including distributed energy management systems, communications infrastructure, and energy storage. The unit cost data are not intended to be directly compared to determine the cost-effectiveness of a given upgrade, but rather as inputs to engineering studies on specific distribution feeders which would provide information on how many units of each type might be required and the degree to which different types of upgrades can be used to expand the hosting capacity of PV. These data are also intended for general understanding and estimation of distribution grid integration costs, rather than specific project planning.

Examples of ways this database could be used by different parties include:

* **PV developers:** Developing estimates of interconnection costs for specific PV systems
* **Analysts:** Improving estimates of costs to integrate PV into the power system and identifying cost drivers
* **Utilities:** Comparing their costs to other utility costs and obtaining additional data about estimate unit cost ranges for emerging solutions that they might not already have access to.

**Organization of each sheet: UPDATED**

In order to make this database more machine readable, we have implemented a common structure for each sheet. This structure is as follows:

--Row 1: sheet title

--Row 2: blank

--Row 3: field names/header

--Remaining rows: data entries

The separate tables within a tab containing cost breakdown data have also been removed. These are now included in a separate file called ‘Cost\_breakdown\_data\_2018.xlsx.’ However, exercise caution when using this database: these are only sub-component costs, not total installed costs for these components. Total installed costs may be significantly higher. Rather than used as the total cost for a component in an analysis, costs in this file may be used, for example, as inputs to a bottom-up cost model of a given component. New cost breakdown data have not been added since the previously release of the database; they have only been moved to this separate file.

We have also removed the legends or keys within the sheets, and instead included the units for upgrade parameters into the field name (e.g. ‘voltage’ is now ‘voltage\_kV’ for voltage regulators, rather than having a separate key describing the units for voltage).

**Summary and Intended Use**

This database contains unit cost information for different components that may be used to integrate distributed PV onto distribution systems. The total cost of implementing different upgrades on a given system is influenced by the number of units required. This is system specific. Additionally, the efficacy of different solutions to mitigate distribution impacts and expand the hosting capacity varies significantly, and thus unit costs should not be generally compared to determine the cost-effectiveness of different upgrade options. Instead, these unit costs should be combined with an engineering analysis of a specific system to understand which upgrades and how many units of each are required to accommodate different levels of distributed PV. Examples of how NREL is using this data to estimate total costs on different feeders is included below.

The data in this database was collected from a variety of utilities, PV developers, technology vendors, and published research reports. Where possible, we have included information on the source of each data point and relevant notes. In some cases where data provided is sensitive or proprietary, we were not able to specify the source, but provide other information that may be useful to the user (e.g. year, location where equipment was installed). NREL has carefully reviewed these sources prior to inclusion in this database.

The database includes information on the categories of upgrades listed in the table below. The specified party/parties who provided the data correspond to those groups that originated the cost estimate, not necessarily the group from which NREL received the data. For example, data pulled from PV interconnection reports obtained from PV developers is still labeled as utility-sourced data, since the utility rather than the developer came up with the cost numbers in the interconnection reports. Some high-level notes on data sources and data quality are provided here. Additional notes on specific data points are included within the database itself.

This database is focused on hardware and software costs. Soft costs (e.g. permitting, interconnection studies) and other overhead costs are not included and should be accounted for separate in any analysis. Additional engineering costs may also be incurred, depending on the scenario, and thoughtful construction of analysis cases/scenarios is always required to obtain results representative of costs that could be observed in practice.

Some data relates to technologies at an earlier stage than others. In particular, Distributed Energy Management Systems (DERMS) is an emerging technology which currently has no standard definition or functionality. Cost vary substantially depending on the project specifics, existing infrastructure (e.g. communications and enterprise systems) of the utility, the functionality included, and the number of DER being managed. This also varies by vendor, and not all vendors or DERMS functionalities are represented in our database. Finally, there may be some costs associated with DERMS that are not captured here including, for example, the cost of training utility engineers on how to operate the DERMS or any overhead costs associated with re-organization. These can be a substantial portion of cost in some scenarios, but would decrease after the first deployment with a given utility.

Even for more mature technologies, some may undergo innovation to reduce cost. Unit costs in this database are only intended to be representative estimates for a given location or vendor for the date specified.

**Important note on dollar years and inflation**

**All costs in the database are in the same dollar year as the date listed.** For example, if the date field says ‘2014,’ the costs are in 2014 USD. **For analysis or comparison of unit costs, all data should be converted into a common dollar year by adjusting for inflation as needed**.

**Note about low, mid, and high cost numbers in the database**

In some of the sheets, an entry (row) in the database may have a low, mid, and high cost number associated with it. These represent the range of costs from the specific data source associated with that entry or row, not the range of costs for that type of upgrade generally (e.g. across the United States or all data collected). For the tabs where some sources provided a range and others provided only a single data point, the single data points are categorized as mid. **However**, **these cost ranges do not capture the full range of costs that might be observed for any given scenario.** For example, for some data, we only have information for certain locations in the U.S. and costs may be more or less expensive for other regions. Additionally, costs will vary by utility and vendor. Additionally, we do not have quotes from an exhaustive list of product vendors for all upgrades.

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| Category | Primary Data Sources | Version 1 Data Quality Notes | Changes in Version 2—2018 |
| Voltage regulators | Utilities: publicly available utility cost guides, SGIP reports | 3 data sources, with data from 2014 and 2016. Some missing data on regulator current ratings. | 3 additional data points added  |
| Capacitor banks | Utilities: publicly available cost data from utilities, PV interconnection reports. Range of hardware only costs from a technology vendor are also available. | 8 data sources, with data from 2011, 2015, and 2016. Some missing data on capacitor specifications.  | 1 additional data point added |
| Transformers | Utilities: publicly available utility cost guides, project reports, and PV interconnection reports | 8 data sources, large number of data points. Some specifications missing, but detailed specifications are available for most entries. Data from 2005-2017. | 2 additional data points added |
| Reclosers, relays, & Protection | Utilities: publicly available utility cost guides and PV interconnection reports | 8 data sources, large number of data points for a variety of recloser/switch types.  | 5 additional data points added; tab reorganized to only include feeder protection (substation protection in new tab) |
| Substation Protection Upgrades (previously under Reclosers, Relays, & Protection) | Utilities: PV interconnection reports | 6 data sources. Large number of data points on 3V0 and DTT from PV interconnection reports. Also some data on other substation fault protection upgrades; in some cases unit/component costs could not be disaggregated. | Disaggregated unit costs for 3V0 and DTT so additional data points are available.  |
| Phase balancing | Utilities: PV interconnection reports | Limited: only two data points | No updates |
| Control modifications (to voltage regulating devices) | Utilities: publicly available utility cost guides and PV interconnection reports; some data on controller hardware only from technology vendors | 24 data points from a variety of geographic locations in the United States | 3 new data points |
| Remove or Relocate (Removal and relocation of existing voltage regulation equipment) | Utilities: publicly available utility cost guides and PV interconnection reports | In some cases, utilities reported moving or removing voltage regulating devices as part of the mitigation strategy. 3 data sources from 2011 to 2016. | No updates |
| Conductor (conductor/re-conductoring) | Utilities: publicly available utility cost guides and PV interconnection reports | 4 data sources from 2016. Specific cable types/part numbers specified for some data points, for others only OH or UG and sometimes location (rural or urban) is provided.  | 14 new data points |
| Energy storage | Lazard and GTM | 2 data sources from December 2016 and 2017. Includes total installed cost data for a range of storage technologies and system types. | Updated data from the Q3 2018 GTM U.S Energy Storage Monitor and Lazard 2018 Levelized Cost of Storage report |
| Other Communications and Sensing  | Technology vendors, utilities: publicly available utility cost guides, EPRI | Most data from 2016. Includes unit costs for different communications components (e.g. gateways for field devices, communication bridges). Just one data point with range of communication network infrastructure costs. Infrastructure costs will depend significantly on the type of system used (e.g. fiber optic, wireless, radio) and the existing utility communication infrastructure.  | No updates |
| SVC, STATCOM, & Related (previously ‘D-SVC, D-STATCOM, and Power Regulators’) | Technology vendors, utilities: PV interconnection reports | Very limited data, only 3 data points. More data will be added as available for these emerging technology solutions. | 8 new data points; re-organized |
| AMI | EPRI, the Edison Foundation | 2 data sources, both from 2011.  | No updates |
| DERMS and Demand Control (previously ‘SCADA, DMS, DERMS’) | Technology vendors, utilities: PV interconnection reports | Data sources from 2012 to 2017 (most from 2016 and 2017). In some cases, costs were back calculated or estimated from reports. Most data is on DERMs or SCADA. DERMs functionality varies across vendors.  | Removed component cost data so it was not used in isolation. 1 new DERMS data point, 1 prior data point updated.  |
| Telemetry and SCADA |  | New tab. Previously under ‘SCADA, DMS, DERMS’ or ‘Communications and Sensing’ | No updates to data, only re-organized |
| Service and metering | Utilities: publicly available utility cost guides and PV interconnection reports | 4 data sources from 2015 and 2016. Data on specifications (e.g. voltage of connection) is missing for some sources. | 2 new data points |
| O&M and component lifetimes | Technology vendors, tax guidelines, private consulting companies, IEEE | Some data is provided to give a sense of the order of magnitude of the lifetime differences between different technology classes only. Extreme caution is required when using any of this data, as O&M and component lifetime data is sparse, the effects of PV on device O&M and lifetimes is not well known or documented, and O&M and lifetimes can vary significantly even without the presence of PV due to differences in operating conditions (e.g. temperature, humidity, loading). In some cases, data represents only the useful life determined previously for tax purposes. | No updates |
| Advanced inverters | Inverter manufacturers, PV developers | The cost of advanced inverters depends on whether the capability of inverters as installed (e.g. if a retrofit of the inverter is required to obtain desired functionality versus just a setting change which could be performed remotely). We include several different scenarios in the database, but there is some uncertainty around these costs.  | This tab was removed. Please see discussion of advanced inverter costs in our technical report: <https://www.nrel.gov/docs/fy18osti/70710.pdf>  |

**How We Are Using this Data at NREL**

We are using this data at NREL to conduct bottom-up analysis of costs that might be incurred on distributions systems to integrate high penetrations of PV under a variety of technology scenarios. We are using an iterative hosting capacity approach for this analysis. Below is a link to publication describing NREL’s approach:

<https://www.nrel.gov/docs/fy18osti/70710.pdf>

**Data gaps and needs**

We are seeking additional data on any components related to integration of PV onto distribution systems to include in this database. In particular, we are seeking additional data on:

* Data on DERMS or ANM costs
* Data on ADMS project costs
* Data O&M costs and component lifetimes for different components, and how the presence of PV affects these values
* Data on software and distributed energy management system costs
* D-SVC, D-STATCOM, and power regulators
* Communications and sensing equipment
* Experiences with advanced inverter costs (new inverters, retrofits, enabling existing features)
* AMI

If you are willing to share any data on these components, please contact Kelsey.Horowitz@nrel.gov. We are accepting data on total installed costs of any component in addition to data on specific cost components (e.g. hardware only costs). As discussed above, we are able to include data in the database in an aggregated and/or anonymized way if preferred in order to ensure protection of confidential, business sensitive, or proprietary information, and are open to signing NDAs as necessary. Our team has earned the trust of our industry partners over the course of years of collecting and handling sensitive information related to photovoltaic component and system costs.

**Abbreviations:**

* DTT = Direct Transfer Trip
* 3V0 = zero sequence voltage
* PV = photovoltaic
* NREL = National Renewable Energy Laboratory
* IEEE = Institute of Electrical and Electronics Engineers
* AMI = advanced metering infrastructure
* OH = overhead
* UG = underground
* GTM = Green Tech Media
* D-SVC = distribution static VAR compensator
* D-STATCOM = distribution static synchronous compensator
* SCADA = supervisory control and data acquisition
* DMS = distribution management system
* DERMS = distributed energy resource management system
* O&M = operations and maintenance