# Analysis of 100 Utility SGIP PV Interconnection Studies

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***Abstract* — Sandia National Laboratories (SNL) performed an analysis of 100 Small Generator Interconnection Procedure (SGIP) studies to identify the most common impacts from photovoltaic (PV) system interconnections of 20 MW or less and the impact mitigation costs. This report highlights the discoveries and describes the methodology used to develop the dataset of impacts. It was observed that 44% of facilities that entered the SGIP study processes identified no adverse system impacts. Interconnection topologies were strongly correlated to the presence/absence of adverse impacts. Protection impacts were the most common adverse system impact identified in the dataset.**

***Index Terms* — data analysis, distributed power generation, photovoltaic systems, power system interconnection, power system planning, standards development, statistical analysis.**

## I. Introduction

Sandia National Laboratories (SNL) has performed a survey of Small Generator Interconnection Procedure (SGIP) studies to identify the most common impacts for PV system interconnections and the costs to mitigate adverse system impacts. The definition of an adverse system impact is a negative effect due to the interconnection of a generation facility (GF), which compromises the performance, reliability or safety of the existing electrical power system (EPS). The purpose of this report is to highlight the findings of the survey.

Developed by FERC, the SGIP is a common standard interconnection procedure adopted by many states or used as a guide for developing their own interconnection rules. The SGIP outlines the process a utility and interconnecting customer (IC) must perform before interconnecting a small GF to the electrical power system (EPS). All EPS providers subject to FERC jurisdiction incorporate the SGIP within their Open Access Transmission Tariff (OATT) [1].

The SGIP applies to GFs of 20 MW or less. The SGIP consists of three evaluation procedures: (1) a 10 kW Inverter Process, (2) a Fast Track process (typically 2 MW or less) and (3) a study process [2]. SNL analyzed reports that entered the study process. The goal of the survey was to:

- Classify the interconnection types and facility costs.
- Analyze the types of adverse system impacts.
- Analyze mitigation options and associated costs.

A total of 100 SGIP PV interconnection reports were surveyed. The reports were performed by 7 utilities with four of the utilities filing jointly with a regional transmission operator (RTO). All entities had either adopted the SGIP completely or with some modifications.

## II. SGIP Study Process

The SGIP study process consists of three or four levels of review with more stringent study requirements at each new level. Most small generation interconnection studies are evaluated based on the following process [3]: 1) Feasibility Study (FeS), 2) System Impact Study (SiS), and 3) Facility Study (FaS). Upon the completion of each study a detailed report is prepared and transmitted to the IC.

### *A. Dataset*

The dataset used in the analysis was derived from 100 SGIP cases. Facility sizes in the dataset ranged from 1 MW to 20 MW. Generally, facilities larger than 2 MW and less than or equal to 20 MW enter the study process by default. Facilities found in the dataset less than 2 MW entered the study process by failing one or more of the 10 Fast Track Screens. Specifically, the five Fast Track Screens relevant for facilities in the dataset that were screened were:

- The small generation facility's capacity must be less than 15% of the peak load on the line section.
- The total small generation facility's contribution to fault current shall not exceed 10% of the distribution circuits' maximum fault current.
- The addition of the small generation facility must not cause distribution equipment to exceed 87.5% of short circuit interruption capability.
- The capacity of the small generation facility shall not exceed 10 MW if interconnecting to an area with known transient stability limitations.
- No construction of facilities by the Transmission Provider on its own system shall be required to accommodate the small generation facility.

The dataset is a compilation of information derived from SGIP reports performed by three electrical utilities (PNM, APS, and PacifiCorp) and one regional transmission operator (PJM). SGIP reports found in the dataset represent facilities at various stages in the study process. Costs/impacts identified in the dataset were derived by using the costs reported in the most recent SGIP report.

SGIP reports were accessed through online data sources and are publicly available. Specifically, PNM [4], APS [5] and PacifiCorp [6] reports were accessed through their respective online interconnection queue datasets, which are available through the webOASIS website. PJM reports were accessed through PJM's online interconnection queue dataset found on PJM's website [7].

### *B. Utility Details*

PNM Resources is an investor-owned energy holding company that operates within New Mexico. Servicing 498,700 electrical customers within New Mexico, PNM Resources is the state's largest electrical provider. SGIP studies obtained from PNM were accessed through PNM's West Trans Oasis (oatioasis.com) webpage. The dataset contains 26 SGIP studies from PNM.

A subsidiary of Pinnacle West Capital Corporation, APS serves over one million customers mainly in northern and central Arizona. SGIP studies obtained from APS were accessed through APS's West Trans Oasis (oatioasis.com) webpage. The dataset contains 13 SGIP studies from APS.

Through its three subsidiaries: Pacific Power, Rocky Mountain Power, and PacifiCorp Energy; PacifiCorp serves approximately 1.8 million customers across six western states. SGIP studies obtained from PacifiCorp were obtained through its West Trans Oasis (oatioasis.com) webpage. The dataset contains 37 SGIP studies from PacifiCorp.

PJM is a Regional Transmission Operator that coordinates the movement of wholesale electricity for all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. With the permission of FERC PJM currently processes interconnection requests according to its own developed interconnection procedures, which are largely based on the SGIP. The dataset contains 24 SGIP studies performed jointly by PJM and 4 electrical utilities. The 24 studies used in the dataset represent a small fraction of SGIP reports available through PJM's queue dataset. The four utilities are: Jersey Central Power and Light (JCP&L), Atlantic City Electric (ACE), First Energy, and Public Service Electric and Gas Company (PSE&G).

### *C. Interconnection Topologies*

The interconnection topologies identified in the SGIP reports were binned into 3 categories: Tap Existing Low Voltage Distribution Circuit, Build New Distribution Circuit from Substation, and Tap Existing High Voltage Distribution Circuit.

Facilities were binned within the Tap Existing Low Voltage Distribution Circuit category if the GFs proposed PCC was located on a distribution circuit that was currently serving customers. Nominal system voltage at the PCC ranged from 12.47 kV to 34.5 kV. Interconnection facilities required for this configuration generally included short spans of conductors with associated poles, metering and communication equipment. Fig. 1 is a one line diagram illustrating a GF interconnecting through an existing distribution circuit.

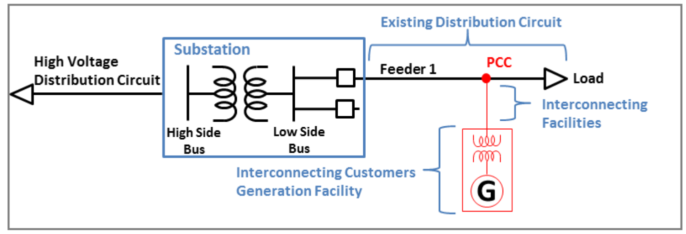


Fig. 1. Tap existing low voltage distribution circuit topology.

Facilities were binned within the "Build New Distribution Circuit from Substation" category if the report identified the need to construct one or more distribution feeders from the Substation to the GF. This interconnection topology is a general term which is composed of two distinct interconnection topologies: single feeder service and double feeder service. Fig. 2 illustrates the circuit topology for facilities requiring Single Feeder Service.

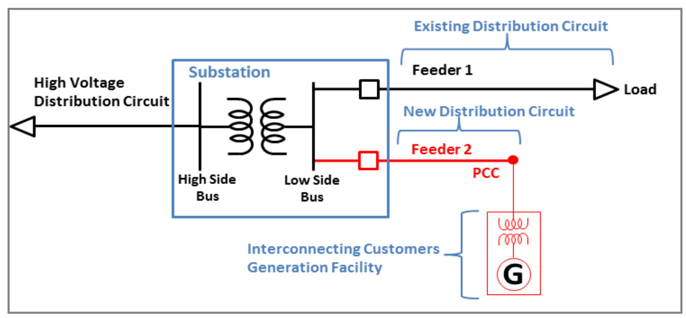


Fig. 2. Single feeder service interconnection topology.

Facilities were binned within the double feeder service topology if the SGIP study identified the need to split the output of the GF between two distribution feeders, one specifically constructed to service the proposed GF. Double feeder service topologies essentially require two PCCs for the interconnecting GF. Three SGIP studies in the dataset required double feeder service topologies to interconnect. Fig. 3 illustrates the circuit topology for facilities requiring Double Feeder Service.

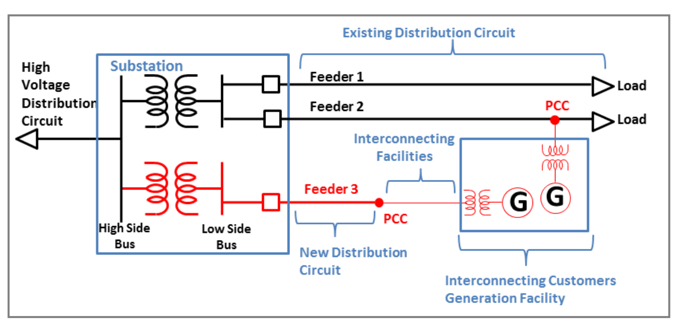


Fig. 3. Double feeder service interconnection topology.

Facilities were binned within the “Tap Existing High Voltage Distribution Circuit” category if the PCC of the GF was located on service distribution circuits interconnecting through the high side of the substation transformer. The nominal system voltage for the EPS at the PCC for these facilities was 69 kV or less. Fig. 4 illustrates a typical circuit topology for facilities interconnecting through existing high voltage distribution circuits.

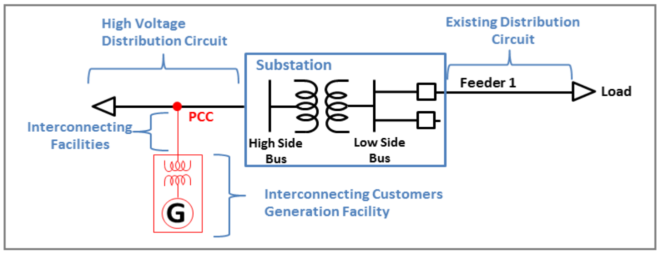


Fig. 4. Tap existing high voltage distribution circuit.

## III. GENERAL STATISTICS

This section illustrates general statistics of the dataset. Fig. 5 identifies the studied facilities by generation capacity and EPS provider. As indicated in Fig. 5, 66% of studied facilities had generation capacities of less than 7 MW. Furthermore, over 82% of the SGIP reports in the database identified generation capacities of less than 11 MW.

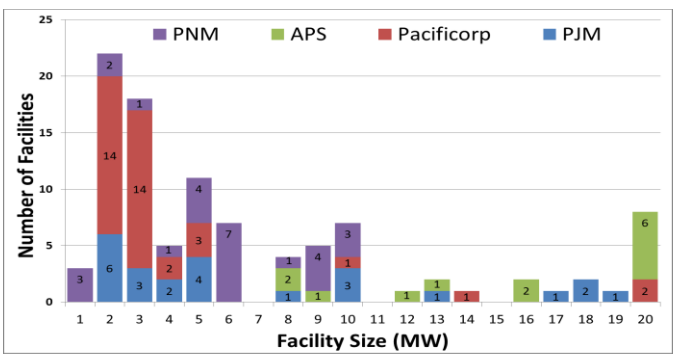


Fig. 5. Generation capacity binned by MW.

The number of SGIP reports binned by interconnection voltage is illustrated in Fig. 6. The interconnection voltage is defined as the operational voltage of the electrical system at the PCC. 70% of the facilities found in the dataset interconnect to the 12.47 kV level. All SGIP reports that identified interconnection voltages of 69 kV had 20 MW generation capacities.

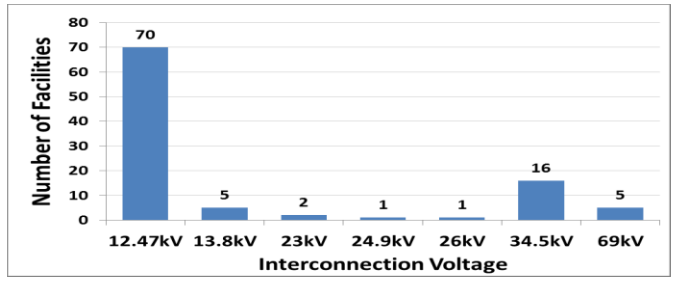


Fig. 6. Facilities binned by interconnection voltage.

A breakdown of interconnection topologies by generation capacity is shown in Fig. 7. Interconnection Topologies were largely dependent on the generation capacity of the GF. All SGIP reports that identified interconnecting through existing low voltage distribution circuits had generation capacities of 10 MW or less. Also, the majority of SGIP reports that identified interconnecting through existing high voltage distribution circuits had generation capacities of 20 MW.

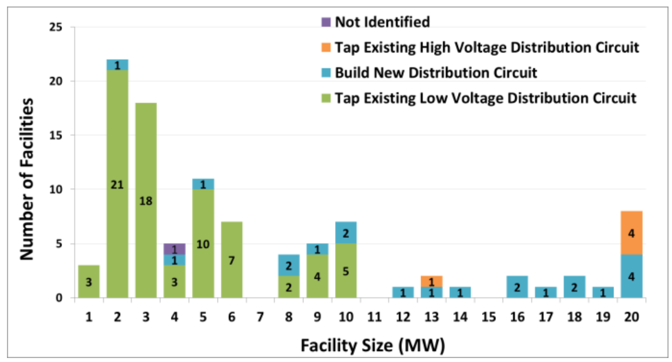


Fig. 7. Interconnection topology by facility size.

### *A. Impacts Identified*

Interconnection topologies were strongly correlated to the presence/absence of adverse impacts. Fig. 8 highlights adverse system impact by two interconnection topologies: tap existing low voltage distribution circuit and tap existing high voltage distribution circuit. Generally, adverse system impacts are more probable if a GF is interconnecting through an existing distribution circuit (Fig. 8A). 68% of generation facilities that identified tapping an existing distribution circuit caused one or more adverse impacts on the EPS.

As indicated in Fig. 8B, only 3 Facilities (14%) that identified interconnecting through new distribution circuits identified an adverse effect on the existing EPS. Building new distribution circuits essentially limits the amount of existing equipment exposed to possible adverse system impacts.

As a whole, regardless of interconnection topology (Fig. 8C), 44% of SGIP studies identified no adverse system impact.

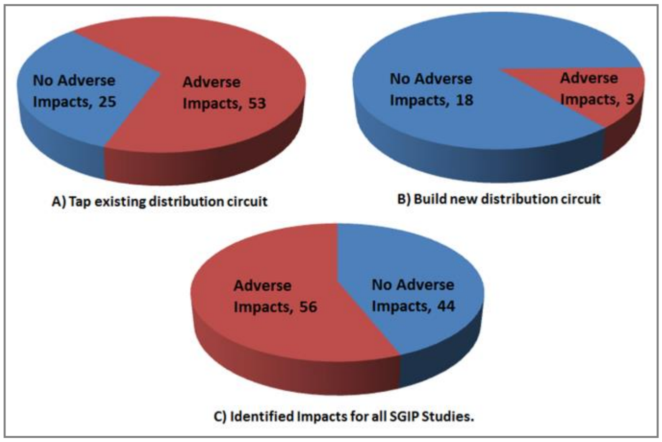


Fig. 8. Incidence of impacts.

Three main impacts were identified in the SGIP reports – voltage, thermal overload, and protection. Fig. 9 shows the SGIP reports binned by identified impacts. Detailed research within each impact category and the mitigation techniques used, as well as costs associated with each, can be found in [3].

All thermal overloads occurred in conjunction with other impacts. 29 SGIP reports identified voltage impacts, 19 of which were overvoltage impacts and 10 were voltage deviation impacts. Protection impacts were the most prevalent with 43 cases.

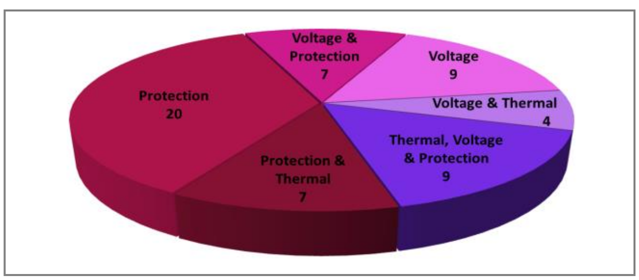


Fig. 9. SGIP reports binned by identified impacts.

*B. Impact Mitigations and Costs*

Mitigation for overvoltage impacts were accomplished through the use of inverter PF correction, LTC adjustments, voltage regulation control modifications, and voltage regulation equipment modifications. 15 of the 19 reports identifying overvoltage impacts provided mitigation costs. 9 reports required only PF correction at the inverters to mitigate the identified overvoltage impacts. The remainder of the reports required a combination of inverter PF correction and other mitigation strategies. Fig. 10 shows the proportion of overvoltage mitigation costs with respect to total interconnection costs.

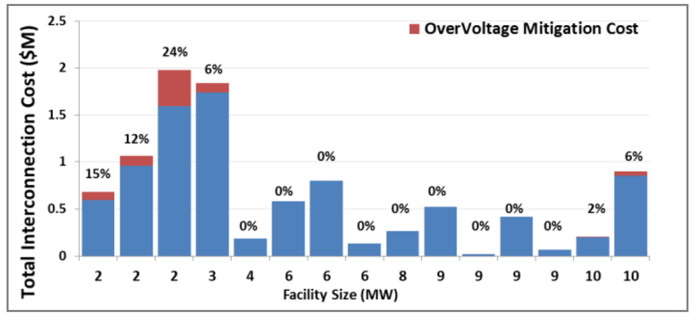


Fig. 10. Overvoltage mitigation cost proportions.

Facilities in Fig. 10 with zero mitigation cost represent the SGIP reports that mitigated overvoltage impacts with inverter PF correction, roughly half. Utilizing the GF's inverters to regulate reactive power provided the added benefit of imposing no added cost to the utility for mitigating overvoltage impacts. Mitigation costs for overvoltage impacts ranged from 0% to 24% of the total interconnection cost, as shown in Fig. 10. Actual costs for overvoltage mitigation ranged from $0 to $383,700.

10 SGIP reports identified a voltage deviation impact. Voltage deviations were defined as a voltage change greater than 3% at any location on the circuit between the basecase and the case with PV. Fig. 11 shows the proportion of mitigation cost to total interconnection costs for 8 of the SGIP reports that identified costs for mitigating voltage deviation impacts. Mitigating voltage deviations required a combination of mitigation strategies including: installing new voltage regulator equipment, modifications to voltage regulator equipment locations, and conductor upgrades.

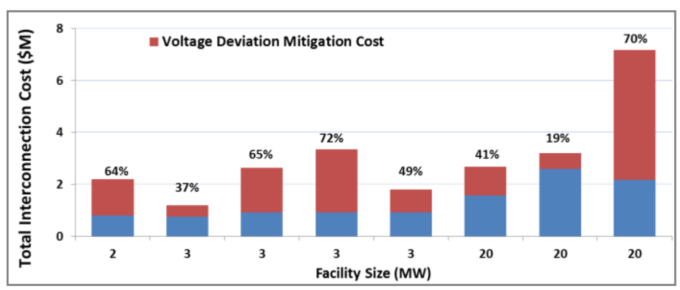


Fig. 11. Voltage deviation mitigation cost proportions.

Due to unique mitigation techniques, voltage deviation impacts were identified as being some of the most expensive to mitigate. One study identified the need for a 5 MVAr Static VAr compensator. Two other studies identified voltage deviations at the substation bus requiring the installation of voltage regulators on all substation feeders. Mitigation costs for voltage deviation impacts ranged from 19% to 72% of the total interconnection cost, as shown in Fig.11. Actual cost for voltage deviations ranged from $434,800 to $5,000,000.

20 SGIP reports identified thermal overloads requiring mitigation. 16 SGIP reports provided mitigations costs for thermal impacts. The proportion of mitigation to total connection costs for reports that identified mitigation costs are illustrated in Fig. 12.

The majority of thermal impacts occurred on feeder conductor sections. 4 SGIP reports required both upgrades to conductor sections and upgrades to voltage regulator equipment to mitigate thermal impact violations. Mitigations costs for overvoltage impacts ranged from 4% to 72% of the total interconnection cost. Actual costs for thermal mitigation ranged from $20,000 to $2,415,100.

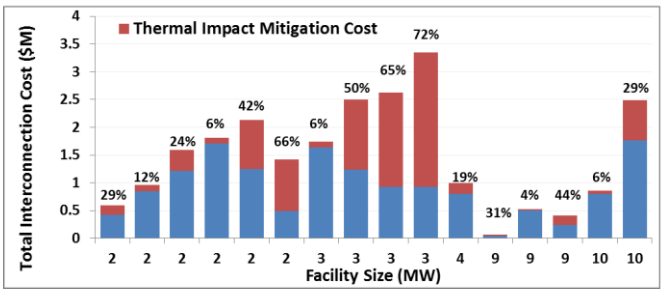


Fig. 12. Thermal mitigation cost proportions.

43 SGIP reports identified protection issues requiring mitigation. Mitigation for protection impacts were binned into two categories substation relay modifications and distribution protection modifications.

Substation relay modifications included adjusting existing relay settings, implementing advanced relay functions such as deadline checking and transfer trip protection and installing protective relaying on the highs side bus to protect against faults on the high side of the distribution substation. Distribution protection modifications included modifications to existing reclosers, or the installation of new reclosers on the existing distribution circuit.

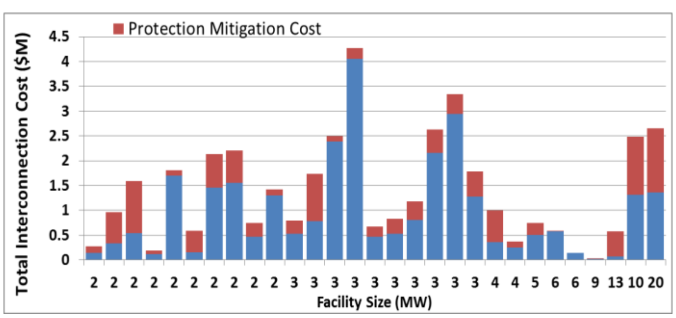


Fig. 13. Protection mitigation cost proportions for substation relay modifications.

Fig. 13 highlights mitigation costs for SGIP reports that mitigated protection impacts through the use of substation relay modifications. Mitigations Costs ranged from $2,000 to $1,300,000 and had mitigation cost rations of 1% to 88% of the total interconnection cost. The large mitigation cost variation was attributed to the fact that implementing advanced relay functionality did not conform to a standard procedure. Some implementations only required communication lines from the substation to the GF while others required major construction modifications at the substation.

Fig. 14 highlights mitigation costs for SGIP reports that mitigated protection impacts through the use of distribution protection modifications. Two SGIP reports identified the need to install more than one recloser to mitigate the identified protection impacts. Mitigations costs ranged from $45,000 to $178,900 and had mitigation cost ratios of 11% to 69% of the total interconnection cost.

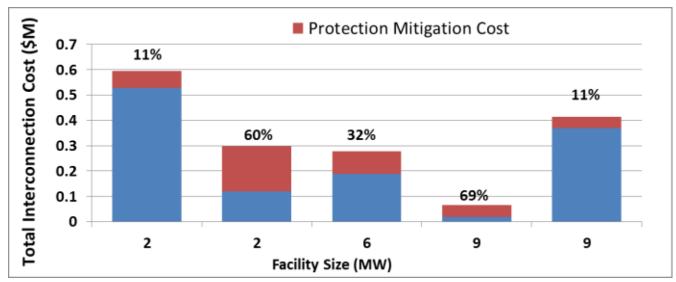


Fig. 14. Protection mitigation cost proportions for distribution protection modifications.

*B. Cost Analysis*

The analysis highlighted in this section is restricted to 90 SGIP reports which provided enough information to identify costs associated with interconnection. Total Connection Costs vs. Facility Size for all SGIP reports in the subset is illustrated in Fig. 15. Each data point is further subdivided by color to identify the interconnection topology. Total connection cost is defined as the sum of mitigation and interconnection facilities costs. Fig. 15 shows total connection costs ranging from $22,000 to $11,516,445. 50% of SGIP studies identified a total connection cost of less than $689,431.

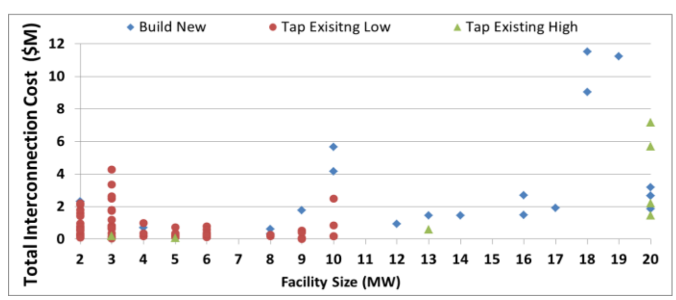


Fig. 15. Total connection costs vs. facility size.

Total Connection Cost vs. Interconnection Voltage for all SGIP reports is represented in Fig. 16. The three most expensive GF identified in the dataset are found in the 12.47 kV class. The two least expensive facilities with Total Connection Cost of $22,000 and $29,150 are found at 13.8 kV and 34.5 kV respectively. Over all, no correlation between voltage class and connections costs were found.

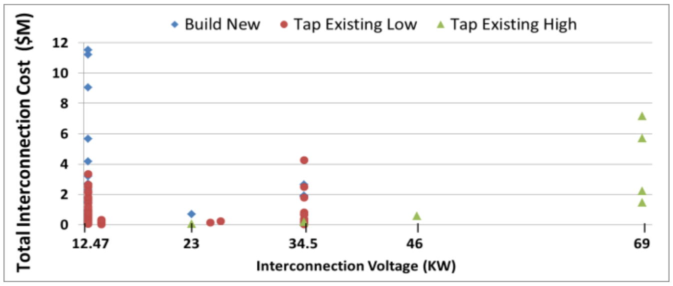


Fig. 16. Total interconnection cost vs. interconnection voltage.

The price per MW for all interconnection types is illustrated in Fig. 17. The Total Connection Cost per MW ranged from $2,444 per MW to $1,424,400 per MW. The largest price variation occurs for 3 MW facilities which ranged from $8,833 to $1,424,400. 50% of facilities have a total cost per MW of less than $133,833.

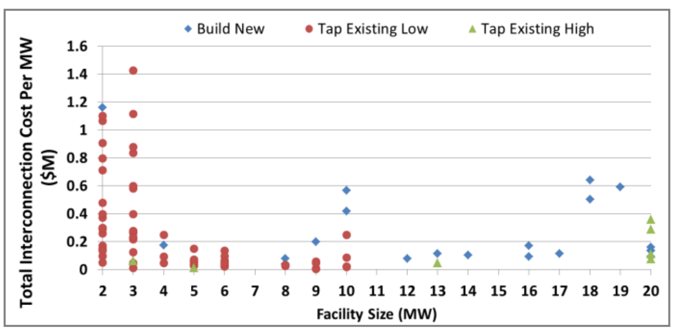


Fig. 17. Total interconnection cost per MW vs. facility size.

## IV. Conclusion

It was observed that interconnection topologies were strongly correlated to the presence/absence of adverse impacts. Generally, adverse system impacts were more probable if the GF interconnected through an existing distribution circuit. Building new distribution circuits essentially limits the amount of existing equipment exposed to possible adverse system impacts.

Protection impacts were the most likely adverse system impact identified. The majority of protection impacts are associated with transfer trip requirements to protect against GF islanding. Transfer trip concerns were largely EPS dependent. Mitigation cost for protection impact associated with advanced relay functions ranged from $74,600 to $1,300,000 [3].

Overvoltage impacts were overall the easiest and least expensive to mitigate, with almost half requiring no added cost. Voltage deviation impact mitigations were much more difficult and costly.

SNL is conducting research with the intention of improving interconnection screens. As this report showed with a sample set of 100 cases, 44% of the requests forced into the study process identified no negative impacts. SNL is also conducting research in identifying the most efficient mitigation strategies for common impacts. Future work will also take into consideration the potential screening improvements provided by the new FERC Fast Track eligibility [9] table which adds voltage, conductor capacity, and locational aspect to the screening criteria for interconnection requests.

## ACKNOWLEDGMENT

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