


Xcel Energy

NSPM Network Connected PV Recommended Practice

Based on
Evaluation of Industry
Practices, Standards and Experience

Sponsors:
System Planning and Strategy (NSPM)
Electric Distribution System Performance (EDSP)

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NSPM Network Connected PV Recommended Practice

1. Scope and Summary

The following is a review of current standards and practices for the interconnection of PV to area and spot secondary networks, with proposed guidelines based on industry practices as well as Xcel Energy’s experience. Descriptions of networks for both spot and grid are found in IEEE 1547 definitions and should be utilized for this document. For the purposes of this document, DG should be understood as inverter based PV generation.

2. Industry Standards, Guidelines or Processes Covering Secondary Network


The IEEE 1547 series of technical standards provides the requirements and recommended practices for interconnection of distributed resources (DG) to the utility distribution system; with the series covering inverter based generation interconnects to secondary networks. The specific documents covering secondary networks are IEEE 1547 which is an industry “Standard for Interconnecting Distributed Resources with Electric Power Systems”, IEEE application guide 1547.2 for IEEE 1547 and 1547.6 being the “Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks”. The 1547 standard and associated recommended practices or application guides do not directly establish DG limits, but provide recommendations relevant to the performance, operation, testing, safety considerations, and maintenance of the DG interconnection to a secondary network. Guidance does however indirectly imply or point to reasonable levels of inverter based generation that can be applied to spot networks.

Along with the 1547 series, the FERC Small Generation Interconnect Process (SGIP) is a process that is commonly reflected in state PUC rules developed or revised after FERC’s approval of the SGIP in 2006. FERC’s Small Generation Interconnection SGIP provides for application screens for spot networks, as well as a process to study proposed DG installations that do not pass the SGIP screens.

2.01. Spot Network Screen (Aggregate Network Installed DG)

In FERC’s SGIP screens, for interconnection of a proposed Small Generating Facility to the load side of spot network protectors, the proposed Small Generating Facility must utilize a certified inverter-based equipment package and, together with the aggregated other inverter-based generation, shall not exceed the smaller of 5 % of a spot network's maximum load or 50 kW¹. The network relay’s power characteristic are usually tilted and offset to some degree for real power flows in the reverse direction, but remain highly sensitive to three phase reverse power flows. With such sensitivity, the introduction of generation on the secondary network has the potential of creating non-fault related power flows in the reverse direction that can cause network protectors to open. Generalized analysis of network relay settings result in a criteria that network protector will open for reverse power of 5% or more of the network protector

¹ FERC Small Generator Interconnection Procedures (SGIP), effective August 26, 2006

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rating.² A note in 1547 section 8.1.4.2 indicates that “When required by the authority who has jurisdiction over the DR interconnection, a study may be conducted to determine that all of the requirements of this subclause can be met when the aggregate DR installed on a spot network exceeds 5% of the spot network’s maximum load.”³ It should be noted that for newer network relays, load should be considered the real power component as the network protectors are insensitive to the reactive power component and the current options are usually not sensitive enough to be the limiting element. The 5% limit is based on reasonably meeting the 1547 requirements for distribution secondary spot networks with some of the specific requirements noted below.

“Any DR installation connected to a spot network shall not cause operation or prevent reclosing of any network protectors installed on the spot network. This coordination shall be accomplished without requiring any changes to prevailing network protector clearing time practices of the Area EPS.”

“Connection of the DR to the Area EPS is only permitted if the Area EPS network bus is already energized by more than 50% of the installed network protectors.”

“The DR output shall not cause any cycling of network protectors.”

2.02. Grid Network Screen (Aggregate Network Installed DG)

IEEE Industry standards and the FERC SGIP do not address grid or area network screens to be applied. In a limited review of various state rules, some PUC’s have used the spot network 5% screen based on maximum load and applied it to area networks.⁴ Typically a maximum limit for grid networks without detailed study applied is 500 kW. Texas utilizes a screen of 25% of minimum grid load⁵ and in Connecticut; a screen using 3% of total area (grid) network maximum transformer connected kVA has been utilized as reflected in the interconnection requirement below.

“A Generating Facility proposed to be interconnected to the load side of an Area Network protector must utilize an inverter-based equipment package and, when aggregated with other inverter-based generation, shall not exceed 50 kW at any location. A location is defined as any manhole or service box. This criteria is designed to ensure that no more than 50 kW of DG is located between the same set (s) of cable limiters. In addition, the aggregate DG interconnected to an area network will be limited to 3% of the maximum network transformer connected kVA with the feeder supplying the largest number of network units out of service, or a maximum of 500 kW, whichever is less.”⁶


² P1547.6 Minutes February 2-3 2006 Page 21

³ IEEE P1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

⁴ Pa Code 75.40, Level 4 Interconnection review; IL PUC, Title 83 Section 466.80 Level 3 review,

⁵ Texas State PUCT Rule 25.211, Interconnection of On-Site Distributed Generation (DG)

⁶ The Connecticut Light and Power Company and The United Illuminating Company Generator Interconnection Technical Requirements

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A similar 3% maximum can be found in EPRI training material and notes that it is subject to further deliberation.⁷ This limit is based on the settings of a non-time delayed directional overcurrent network protector relay (MPCV) using typical settings. The 3% criteria looks at the maximum inverter based generation that can be accommodated with typical settings and equivalent network transformer X/R ratio. It assumes that under a three phase fault condition on an adjacent substation feeder (non-network), the network load will draw no power due to low voltage and that inverter generation will be a constant current source feeding back into the network protector. With inverter levels above approximately 3% of connected kVA capacity, the study indicated that this backfeed could cause the network protector to open.

Both limits are similar considering that the desired peak loading on a network transformer is approximately 60-70% of nameplate, using 5% of 60% of the nameplate ratings results in 3% of nameplate. Limits based on maximum load or transformer capacity are easier to implement due to more readily available information on network maximum loads and connected capacity.

2.03. Spot and Grid Network Facility Level Screen

IEEE Industry standards and the FERC SGIP do not directly address grid or area network facility level screens that can be applied. However some direction is provided in the 1547.2 application guide to 1547 and by other Utility applied criteria.

The Application Guide suggests that for spot networks that “if the prevailing practice of the utility does not to allow time delay of network protector tripping for reverse power conditions, only insignificant amounts (less than 25% of the minimum load) of inverter-interfaced, and load-coincident, generation can be installed. Inverter-based DR have the advantage that fault current is very limited (to about 100% to 200% of normal load current). In addition, an inverter can respond rapidly to signals that control its power output level. To avoid protector cycling, the exact load point at which tie-line control must be initiated has to be determined based on the minimum loading of the lightest-loaded protector serving the spot network (i.e., the facility minimum divided by the ratio of the minimum protector to average protector load).”⁸


“If DR generation exceeds the onsite load, even momentarily, power flows from the network toward the primary feeders, and the network relays will open their network protectors and isolate the network from its EPS supply. Minimum site loads (e.g., late at night or on weekends) may severely limit the size or operating hours of a DR. Even if a DR is sized to the site’s minimum load, consideration has to be given to the possibility of a sudden loss of a large load, which might reverse power flow through the network units.”⁹

Recommended practice 1547.6 gives a method to define a screen by evaluating an acceptable ratio of DG capacity to facility minimum loading. The minimum loading is preferably determined through actual load measurements over a full year of operation. Area networks require additional study of loading at the specific area on a grid network where the PV is to be

⁷ EPRI, Seattle Washington Low-Voltage Network Training Material August 20-22, 2013, Prepared by David R Smith, P.E.

⁸ IEEE P1547.2/D6, Draft Application Guide for IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems, Section 8.1.4.2.3

⁹ Same Reference as 7, Section 8.1.4.2.1

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installed, with the area studied being limited by the surrounding network protectors connecting the specific section of the grid. It is also noted that for new installations or where information is not available, estimates of minimum loading may be used. No recommended ratio is specified or recommended in standards or recommended practices; however it is noted in 1547.6 that one utility specifies a maximum DG capacity up to 1/15th of the facilities measured annual minimum load, which is applied to both spot and grid networks.

2.03.01. Minimum Load Relaying

Facility PV limits can be increased significantly from the facility screen level with the addition of relaying to compare facility loading to PV generation. These relays insure minimum power consumption and are intended to prevent unnecessary network loss due to the potential of power flow back into the network from PV generation. Two types of relays schemes to insure minimum power consumption are the Minimum Import Relay (MIR) and Comparative Relay (CR).

The additions of the MIR or CR relaying have no impact on network limits. Increases above network limits would take a detailed evaluation of relay protective functions, equipment ratings and flows on the network.

3. Existing MN Rules and Criteria

The existing rules and interconnection guidelines provide no screens for the expedited installation of PV systems on networks. The following rules and provisions can be found:

3.01. Minnesota Rules and Interconnection Process

Generation System will not be interconnected with a “networked” system¹⁰


3.02. Minnesota Network PV Pilot Requirements

This pilot project required certified inverters for PV generation and direct connect machines were not allowed. The criteria applied for this pilot are as follows¹¹:

- Additional protective relaying system is not required if:
 - Minimum load > 20 times the generation nameplate as measured instantaneously (Requires previous 12 months of data. Subject to revocation)
 - Protective relaying requirements:
 - Minimum Load Relay (Minimum Import Relay, MIR)
Trip the Generation instantaneously if generation rated output exceeds 25% of the actual service load
 - Comparative relaying system
Prevent the Generation output from exceeding 50% of the service demand

¹⁰ Minnesota Electric Rate Book-MPUC NO. 2, Section 10, Original Sheet No. 87

¹¹ Interconnection of MN Distributed Generation – Technical Meeting May 31, 2012 Division of Energy Resources, Minnesota Department of Commerce Page 7 of 12

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- Protective relaying systems proposed by customer and evaluated for approval by Xcel Energy
- All equipment providing relaying functions shall meet or exceed ANSI/IEEE Standards for protective relays, i.e. C37.90, C37.90.1 and C37.90.2
- Protective Devices and System per Tariff Section 10.

4. NSPM Recommended Practice for Network Connected PV

Based on a review of the industry standards, guidelines, practices and Xcel Energy’s experience with existing network connected PV, the following recommended screens and guidelines are to be used for installation of PV on networks in the NSPM service territory under existing tariffs.

These screens and guidelines should be considered supplemental to the FERC SGIP, with the SGIP process to be followed for Secondary Network interconnects. Any proposed network PV interconnection that passes the screen thresholds can be interconnected with little or no study. There are additional screens in the SGIP for interconnection to distribution systems that are not specifically covered, but apply to all distribution interconnects. The 1547 standard and 1547.6 recommended practices shall be followed to avoid adverse impacts to a secondary network. Failure to pass the screens will require detailed study of the proposed PV interconnect following Level 3 of the SGIP.

Definitions

PV AC rating: The greater of the inverter AC nameplate rating or 95% of the PV DC rating. Systems of multiple inverters and panels shall be aggregated for the basis of determining PV AC rating. (The PV AC rating shall be utilized for the evaluation of all PV power (Volt-Amp) rating requirements in this document. The definition applies to “PV AC maximum capacity” and “inverter-based generation”.)


Customer Load: See Service Load

Facilities Study: A study that determines exactly what must be done to interconnect the facility to the utility electric system, including equipment and costs. This usually follows a system impact study.¹²

Feasibility Study: A preliminary study that can determine if additional facilities are necessary for the proposed project to interconnect to the utility. This study does not go into as much detail as a system impact study and facilities study. This usually precedes a system impact study.¹² For Network connected DR, the impacts of DR on network protector cycling should be reviewed.

Secondary network: An AC distribution system where the secondaries of the distribution transformers are connected to a common network for supplying electricity directly to consumers. There are two types of secondary networks: grid networks (also referred to as area networks or street networks) and spot networks.

¹² Definition from: Interconnection Guidebook For Developers of Small Scale Renewable energy generation systems, EnergyTrust of Oregon

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System Impact Study: A study that focuses on the electric system impacts that would result if the proposed facility were interconnected without modifications. This generally follows a feasibility study and precedes a facilities study.¹²

Grid network: A secondary network system with multiple wires interconnected to separated network units (protectors and relays) designed to serve multiple geographically separate customers. Designed to provide highly reliable electrical service to a group of customers and typical found in downtown areas of major cities. A grid network is also referred to as an area network or a street network. A grid network must be treated as a spot network if there are less than three delivery points

Largest Circuit Verification: The minimum allowable load should be based on evaluating Minimum Loading with the contingency of losing the largest customer(s) largest load center branch circuit with the next largest circuit out for maintenance, with 20-30% margin.


Minimum Load: For PV installations, the minimum daytime load of the customer. Minimum loading should be determined from a long term analysis. An estimate of minimum loading can be obtained through the use of available metering information and/or a short term load recording. Customer usage data generated by sub-metering or building automation systems may be used for this purpose if available and validated. The method used to estimate minimum loading should adequately capture facility off-peak daytime use and should account for seasonal variations. Atypical usage can occur for facilities such as convention centers and sporting facilities. Utility can apply additional margins to minimum load based on data confidence and ability to estimate minimum loading. Minimum daytime usage should be documented by the Utility and verified with interconnecting retail customer. (Definition also applies to Minimum Service Load)

Minimum load relay: A relay that monitors load and generation to ensure that more load than generation is maintained. Relay settings shall ensure no power backflow into the distribution system for both steady state and contingency situations. Relay will trip or curtail generation to maintain sufficient load to generation margins.

Service Load: Service load is the retail customer’s single metered real time load without generation load reductions.

Service Demand: Service demand is the retail customer’s single metered real time load including generation load reductions.

Spot network: A small network, usually at one location, consisting of two or more primary feeders, with network units (transformers, relays and protectors) with one or more load service connections. A spot network usually feeds one customer or part of a building; some may serve more than one building. Typically found within modern commercial buildings such as a hospital, convention center or sporting facility to provide high reliability of service.

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Network Screens for Interconnection of PV

Category ^a	Inverter Based/PV Criteria
Screen for Spot Network	<ul style="list-style-type: none"> PV AC maximum capacity shall be less than 1/15th of the retail customer's Minimum Service Load without application of minimum load relaying. ^b The aggregated inverter-based generation tied to a spot network, shall not exceed the smaller of 5% of a spot network's maximum load without application of minimum load relaying^b or 50 kW without a Feasibility Study.
Screen for Grid Network	<ul style="list-style-type: none"> PV AC maximum capacity shall be less than 1/10th of the retail customer's Minimum Service Load without application of minimum load relaying. ^b The aggregated inverter-based generation tied to a grid network, shall not exceed the smaller of 5% of a grid network's maximum load without application of minimum load relaying^b or 250 kW without a Feasibility Study.

Minimum Load Relaying Options and Criteria:

If the proposed PV does not pass the above screening criteria, the application of one of the minimum load relaying options as listed below will be required.

Dynamically controlled inverters (DCI) can be utilized in combination with minimum load relaying to curtail PV generation prior tripping¹³. Where the impact of an unintentional operation of a network protector is limited to the interconnecting customer's facility, inverter(s) with minimum load relaying functionality may be used upon review and approval by Xcel Energy Engineering during the application process.

¹³ NREL, Photovoltaic Systems Interconnected onto Secondary Network Distribution Systems- Success Stories, Section 5.1, pages 27-30

Minimum Load Relaying Options ^c	Relay Criteria
Minimum Import Relay (MIR)	<ul style="list-style-type: none"> • MIR Relay shall monitor retail customer's Service Load. • MIR relay shall trip or curtail PV generation below set limits when retail customer's Service Load drops to less than 200% of PV system AC rating. • For spot networks, relay settings should be checked against Minimum Load determined by Largest Circuit Verification.^d
Comparative Relay (CR)	<ul style="list-style-type: none"> • CR Relay shall monitor retail customer's Service Demand. • CR Relay shall monitor the aggregate AC generation output of the retail customer's installed PV. • CR relay shall trip or curtail PV generation below set limits when PV generation is greater than 100% of Service Demand. Relay shall trip PV generation prior to reaching Relaying Systems sensitivity or accuracy limits, plus an amount determined by Largest Circuit Verification.^e • For spot networks, relay settings should be checked against Minimum Load determined by Largest Circuit Verification.^d
Other Proposed Control and Relaying Schemes Meeting the Intent of MIR Relaying and IEEE 1547.6	<ul style="list-style-type: none"> • Prior to a full revision to this recommended practice, new technologies may become available meeting the intent of minimum load relaying. This recommended practice allows for an exemption request by Customer for Utility Grade¹⁴ control and relaying schemes meeting the intent of IEEE 1547.6 and this recommended practice. An exemption may be granted upon review and approval by a qualified Xcel Energy engineer. Such requests shall be made during the application process and additional review costs and/or time for project approval are applicable. A cost and time estimate for this additional review can be provided as part of the application review process.

¹⁴ Meet or exceed ANSI/IEEE Standards for protective relays, i.e., C37.90, C37.90.1 and C37.90.2.

Notes:

^a There are additional screens in FERC's SGIP for interconnection to distribution systems that are not specifically covered in this document, but apply to all distribution interconnects. The 1547 standard and 1547.6 recommended practices shall be followed to avoid adverse impacts to a secondary network.


- I. Only certified inverter generation is allowed on a network, direct connect machines are not allowed due to out-of-step voltage withstand, synchronizing, and high fault contribution issues.
- II. Large margins are needed between projected minimum load and maximum PV output unless there is a high speed margin detection system with PV output curtailment. Due to diversity and multiple delivery points, a grid network can safely use smaller multiples for margins.
- III. A grid network must be treated as a spot network if there are less than three delivery points, as the degree of diversity is low and single loads may be a large percentage of the total load.
- IV. PV connections to high density urban grid or spot networks tend to be self limiting by roof space. Most grid networks are in a high density area and will have significant load to offset the generation. Spot networks in other locations can have ample roof space available for PV to cause serious service issues.
- V. Spot networks do not have the load diversity as grid networks and are subject to greater variations in load and can have a single large load on one circuit that is a much higher percentage of the total.

^b If network connected PV, without minimum load relaying, results in notable adverse network impacts, minimum load relaying shall be installed to trip or curtail PV generation. Aggregate network screens take precedence over customer level screens when evaluating an interconnect request.

^c All minimum load relaying functions shall meet or exceed ANSI/IEEE Standards for protective relays. Relaying with margins as specified in this document shall utilize three phase monitoring. Minimum load relaying shall use instantaneous elements with no time delay to trip or curtail generation.

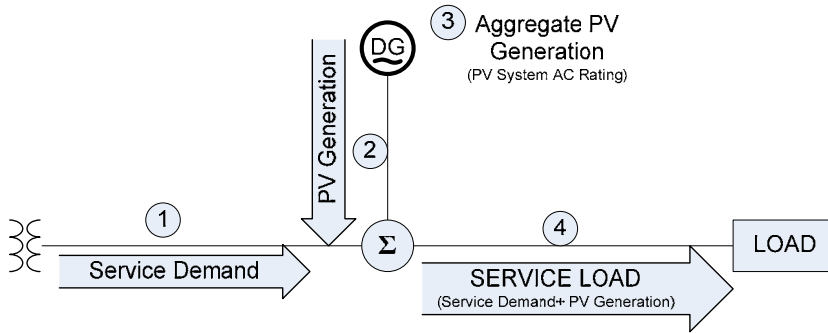
^d Utility shall document calculations of minimum loading with Largest Circuit Verification and review with interconnecting retail customer to obtain agreement. Decreases in documented minimum loading that result in network performance issues as identified in IEEE 1547.6 may require changes to relay settings from those specified. Changes in relay settings may result in increased opening or curtailment of the PV system.

^e A Relay System is an assembly that usually consists of measuring units, relay logic, communications interfaces, computer interfaces, and necessary power supplies (IEEE-C37.100).

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Appendix A

Minimum Import and Comparative Relaying Description



Minimum Import Relay (MIR)

Trip or Curtail When: $\text{Service Load} < 200\% \text{ of PV System AC Rating}$



Comparative Relay (CR)

Trip or Curtail When: $\text{PV Generation} > 100\% \text{ of Service Demand}$

