Design Considerations When AC Coupling IQ Micros to Battery-Based Systems

Overview

AC coupling allows use of Enphase Microinverters with battery-based inverter systems. These applications require a grid-forming, battery-based inverter to create an intentional AC island to which the microinverters can export power.

You can configure a system as an AC-coupled multimode system where the primary mode of operation is utility-interactive with alternate backup or stand-alone functionality. You can also create a stand-alone system and operate off-grid with no utility service present at any time. This configuration is often called a microgrid with AC coupling because the PV system, in this case the Enphase Microinverters and the battery-based inverters, are “coupled” on their AC outputs. In this application, Enphase Microinverters provide energy for the loads and charge the batteries of the battery-based inverter while the grid is unavailable. It is important that the battery-based inverter AC coupling function is enabled to prevent damage to the batteries.

This document describes configuration considerations when AC coupling IQ Microinverters to third-party storage systems that use battery-based inverters operating in both utility interactive and backup applications. Microgrids are not covered in detail in this document.

At the time of publication of this Technical Brief. the Enphase AC Battery and Enphase IQ Battery are not grid-forming. AC coupling of these storage solutions is not covered in this document.

A battery-based application is generally more complex than a purely utility-interactive PV system and requires expert knowledge to be implemented successfully. Installers and designers must be qualified experts before working with battery-based systems and AC coupled systems. This document does not list all of the requirements and qualifications required.

Benefits of AC Coupling Enphase Microinverters

Grid-forming, battery-based inverters require a more sophisticated system design compared to traditional purely utility-interactive PV systems, however they can provide power for grid outages in emergency situations and for remote locations where no grid is present. Given the benefits of AC coupled systems, there are now a number of third-party storage solutions that use a bi-directional inverter to manage the battery storage independent of the PV system. Some of these third-party solutions are fully integrated inverters with storage chemistry, while others require the installer to select the inverter and to select and integrate batteries.

Enphase Microinverters offer advantages over other inverter technologies when AC coupled to a battery-based inverter system. This is because a microinverter system is divided into AC branch circuits of a quantity of microinverters and PV modules that can provide a tapered charge to the batteries. IQ Microinverters provide additional functionality over previous microinverter generations including current- or frequency-based power curtailment when storage and load needs are satisfied, and broader voltage and frequency operating ranges that may be present in a fluctuating microgrid. These features allow for more flexibility for AC coupling than do PV string inverter systems.

Enphase Microinverter systems can be AC coupled to a battery-based inverter system after installation, and the production capacity and backup or stand-alone loads can be increased or reconfigured to fit storage needs. Enphase Microinverters also offer the design flexibility, increased safety, and increased performance that come with module level maximum power point tracking (MPPT) and monitoring.

AC Coupling Configurations

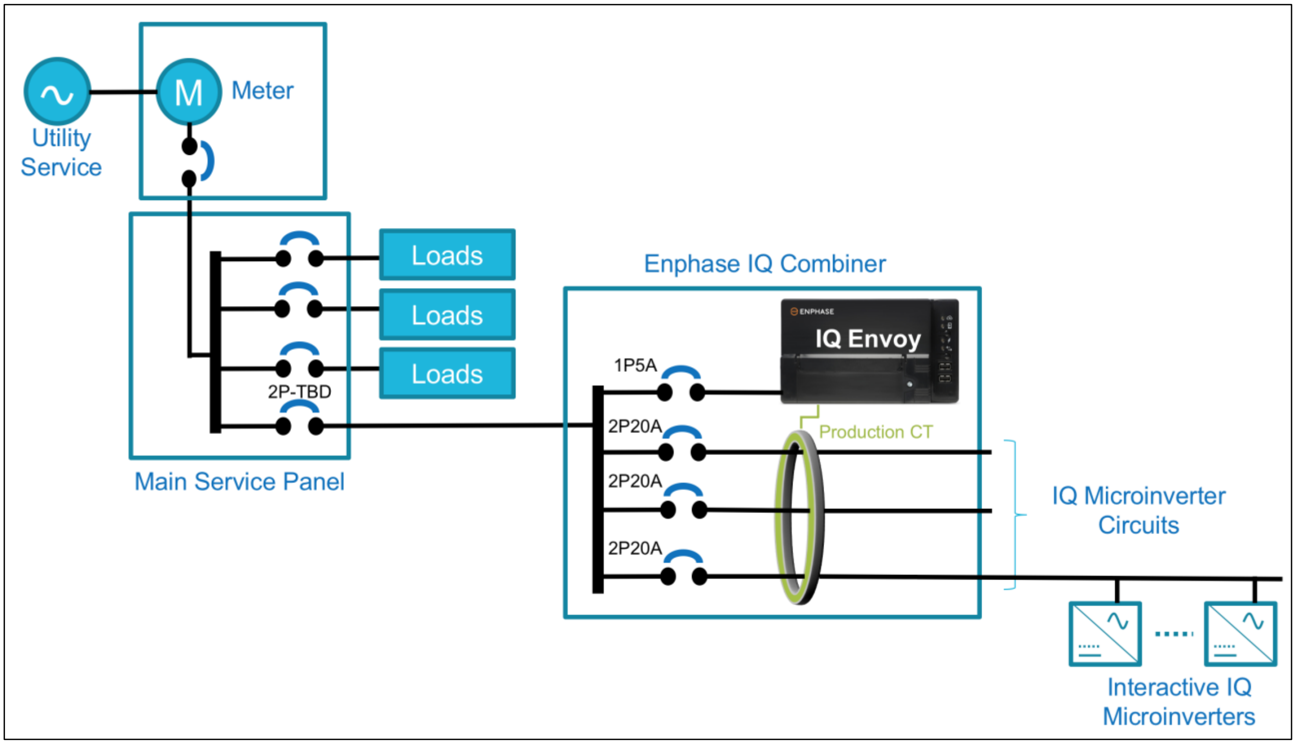
There are three common types of PV system interconnection modes and AC coupling configurations in which IQ Microinverters can be used. The following chart identifies how **microinverter interconnection compliance, PV system curtailment (for battery safety),** and **load considerations** are satisfied in the three different types of interconnection modes.

- Net energy metering: In this type of application the utility-interactive IQ Microinverters are able to export excess PV production to the grid, which generally results in some form of compensation from the utility.
- Export limiting: In this type of application, the utility allows a PV system to be operated so long as it does not export any PV production to the grid or keeps the PV production below a specific power level.
- Microgrid: In this type of application, there is no utility grid service and the IQ Microinverters interconnect to a microgrid formed by one or more generation sources. The primary difference between a utility interactive interconnection and off-grid / microgrid interconnection is that the microinverters are not subject to regulatory interconnection requirements.

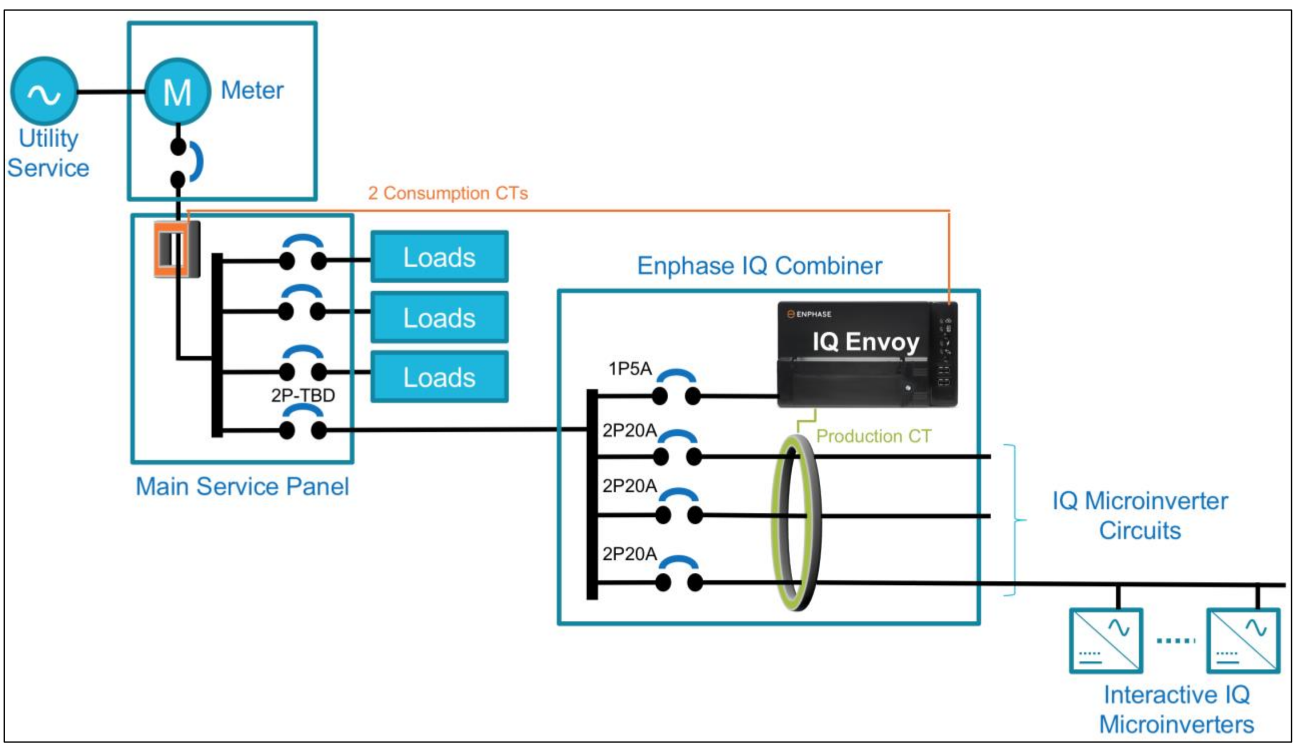
PV System Interconnection Modes		AC Coupling Configurations			
		Utility Interactive	Backup		Off-Grid
			Utility Interactive	Off-Grid	
Net Energy Metering	Microinverter Interconnection Compliance	Local Interconnection Settings	Local Interconnection Settings		
	PV System Curtailment (for Battery Safety)	Not Required	Not Required	For Battery Safety: 1) External Relay Control (full/partial) 2) Frequency/Trip 3) Frequency/Watt	
	Load Considerations	Annual energy use defines PV system size for maximum offset	Annual energy use defines PV system size for maximum offset	Backup Load Analysis: instantaneous power and desired backup period energy consumption define energy storage system size	
Export Limiting (zero export/ set limit)	Microinverter Interconnection Compliance	Local Interconnection Settings	Local Interconnection Settings		
	PV System Curtailment (for Battery Safety)	Power Export Limiting (PEL)	Power Export Limiting (PEL)	1) External Relay Control (full/partial) 2) Frequency/Trip 3) Frequency/Watt	
	Load Considerations	Annual energy use and daily load profile defines PV system (and optional energy storage system) size for best economic offset	Annual energy use and daily load profile defines PV and energy storage system size for best economic offset	Backup Load Analysis: instantaneous power and desired backup period energy consumption define energy storage system size	
Microgrid	Microinverter Interconnection Compliance				Microgrid-specific Interconnection Settings
	PV System Curtailment (for Battery and Generator Safety)				1) External Relay Control (full/partial) 2) Frequency/Trip 3) Frequency/Watt
	Load Considerations				Load Analysis: instantaneous power and desired operating period energy consumption define PV and energy storage system size

Table 1: AC coupling configurations and integration considerations

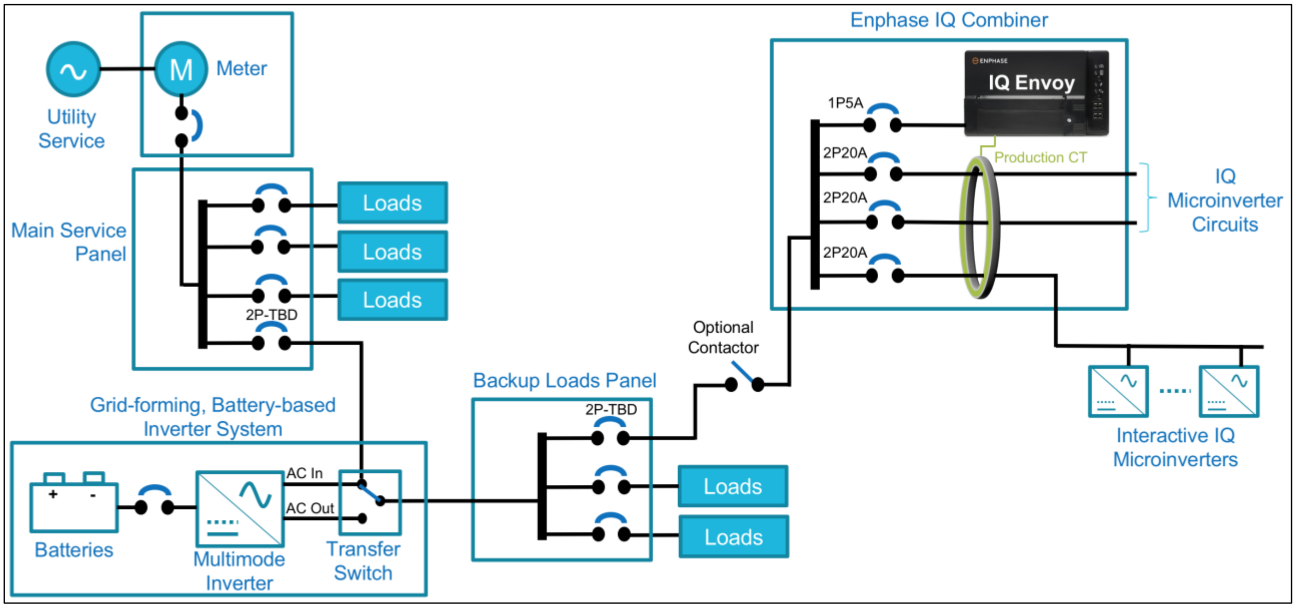
Net Energy Metering, Utility Interactive – Example System Diagram



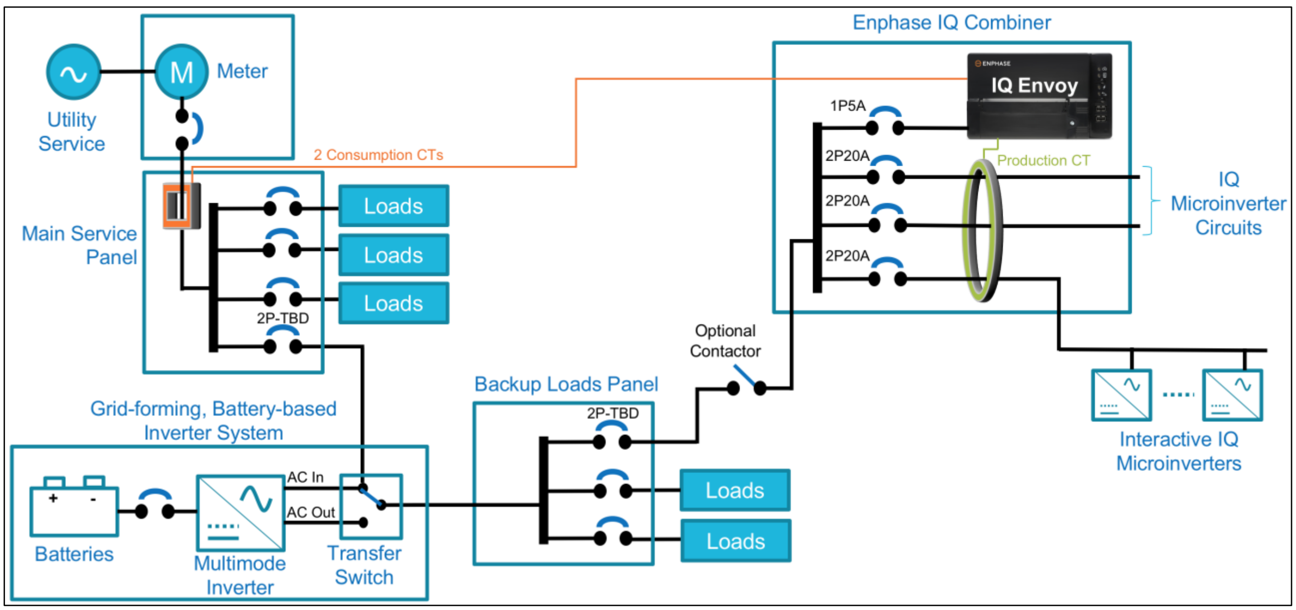
Export Limiting, Utility Interactive – Example System Diagram



Net Energy Metering, Utility Interactive with Backup – Example System Diagram



Export Limiting, Utility Interactive with Backup – Example System Diagram



Microinverter Interconnection Compliance

The specific settings of the interconnection functions of the microinverters in an Enphase system are managed via *grid profiles*. Microinverters in North America ship by default with IEEE 1547 settings defined in the grid profile called "IEEE 1547 default 2015". In geographies where this is the correct profile, you will not need to set this grid profile, but it is good practice to confirm that the correct settings are applied. Grid profiles contain all the settings for microinverter interconnection functionality and are defined in Enphase's Enlighten Manager web-based platform and set on the Enphase Envoy. You can also access these settings in the Enphase Installer Toolkit App for smartphones. This provides flexibility when unique settings are desired either onsite during the installation or remotely via Enlighten Manager. When the utility asks for proof that specific settings were applied, confirmation for each microinverter on the system is provided via the grid profile report from either Installer Toolkit or Enlighten Manager. Note that the IQ Envoy propagates the grid profiles to the microinverters, so it is important to properly setup and connect an IQ Envoy to an Enphase Microinverter system. If the required grid profile is not available on the Enlighten Manager or Installer Toolkit pull down menu, please contact your Enphase Energy Field Applications Engineer to generate a customer grid profile.

Net Energy Metering and Export Limiting – Interconnection Compliance

When utility-interactive microinverters are energized on an electric service, the local interconnection requirements define the voltage, frequency, and anti-islanding functions that inverter systems must comply with. These requirements are set by the authority having jurisdiction (AHJ). In most US states, a Public Utility Commission (PUC) governs the operating rules that the utility service providers must follow when approving interconnection of distributed energy resources, such as PV systems onto their distribution network. In the US and Canada these operating functions are defined by IEEE 1547, with certain additional local requirements such as California Rule 21 and Hawaii Rule 14H defined in a Source Requirement Document (SRD) and approved by the PUC. For a given microinverter model these functions are certified according to UL standards, such as UL1741 or UL1741-SA.

In PV systems with Net Energy Metering (NEM) or defined export limits (zero export or specified export power limit), the interconnection operating functions of the microinverters are the same for utility interactive and backup / off-grid system configurations.

For backup systems, the utility still specifies the interconnection functions, which are set on the microinverters via the grid profile settings. Microinverters continue to operate with these grid profile settings when isolated from the utility service during a grid outage and when AC coupled to the grid-forming, battery-based inverter.

Therefore, the battery-based inverter in the off-grid operating mode must create a microgrid with voltage and frequency ranges within the microinverter interconnection settings if the microinverters are to operate. In this operating mode, the microinverters will generate the full available PV power into the microgrid, and either loads or the battery-based inverter must consume this generated PV power. If the available PV power is greater than the combined required power of the loads and battery-based inverter, then the microinverters need to be curtailed to protect the batteries from over charge and damage.

As specified by the standard IEEE 1547, the inverter closest to the point of common coupling must comply with the local interconnection requirements. When microinverters are AC coupled on the backup loads panel of the system, it is the battery-based inverter that provides the local interconnection compliance. If this is the case, then you can set the microinverters with a grid profile that is optimized for backup / off-grid operation and battery charging.

Microgrid – Interconnection Compliance

When AC coupling microinverters to a battery-based inverter in a purely off-grid or microgrid scenario, you have more flexibility to adjust the microinverter interconnection settings. The grid-forming, battery-based inverter must operate within the capability of a particular microinverter model, and you can set the grid profile on the microinverters to the desired microgrid-specific interconnection requirements.

PV System Curtailment

There are a number of options available for system integrators to ensure that the microinverters curtail output power when needed.

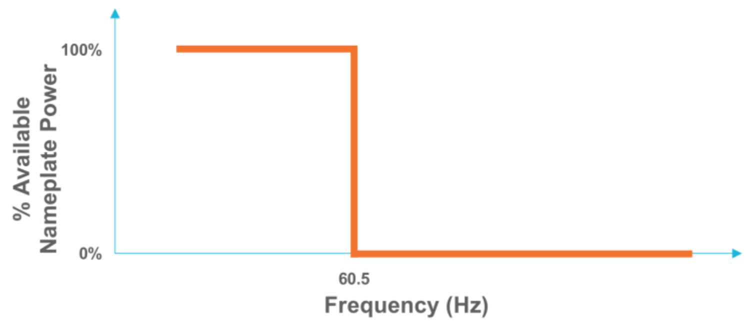
External Relay Control

You can use external relays to measure a source voltage or signal and trigger a contactor to disconnect microinverter AC branch circuits. You can design this to provide **full** or **partial** PV system disconnect and reconnect functionality. Keep in mind that local interconnection settings may have a reconnect timer when the microinverters are returned to the AC grid. For example, IEEE1547 requires a five-minute reconnect period after a good AC grid source is detected before the microinverters can start producing power again.

You can design relays to trigger on battery voltages, detect whether utility provided grid source is available, or trigger from a control signal provided by a battery-based inverter.

AC Frequency / Trip

All local interconnection settings have an over-frequency trip threshold that requires the microinverters to completely stop producing power. Many grid-forming, battery-based inverters have the ability to shift the operating frequency in off-grid mode when their batteries are fully charged. Setting the battery-based inverter over-frequency shift setting to a value above the microinverter system local interconnection frequency trip point, will cause the microinverters to completely stop producing power. When the battery-based inverter detects that battery charging is required again, it will lower the frequency. The microinverters then resume generation after the local interconnection compliance reconnect time setting, e.g., five minutes reconnect timer for IEEE 1547. This type of over-frequency trip function will work with IQ Microinverters and M- and S-Series microinverters.

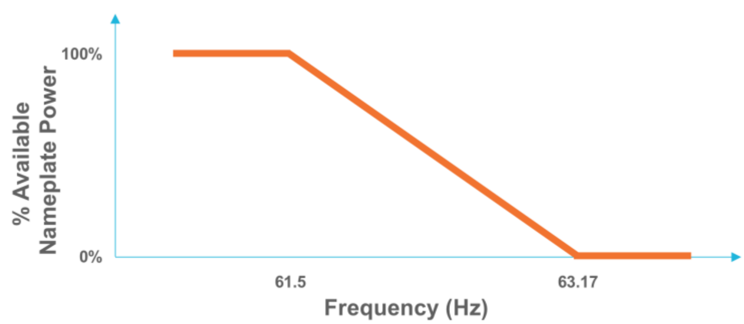


Example: Over frequency trip behavior 60.5 Hz per IEEE 1547

AC Frequency / Watt

IQ Microinverters can gradually curtail power output based on the grid or microgrid AC frequency. This is often referred to as frequency / watt (frequency-based power control), or over frequency power limit. IQ Microinverters back off maximum power point voltage to reduce AC power output, based on the AC frequency. This causes no damage to the microinverters.

Modern battery-based inverters have the ability to gradually change their frequency when operating in off-grid mode when the batteries are reaching a full charge. When this option is enabled on the grid-forming, battery-based inverter, you can set the IQ Microinverters to gradually decrease and increase power output accordingly.



Example: Over frequency power limit (61.5 Hz start, ramp down rate 60 %/Hz)

The following settings define the IQ Microinverter **over frequency power limit**

- Start frequency in Hz (min 60, max 65)
- Start delay in milliseconds (min 0, max 10)
- Ramp down rate in %/Hz (min 40, max 83.33)

Note that the local interconnection compliance requirements must allow this type of over-frequency operating behavior when the microinverters are interconnected to a utility-provided grid source. If these types of settings are not part of the local interconnection settings, you must use a different PV system curtailment method.

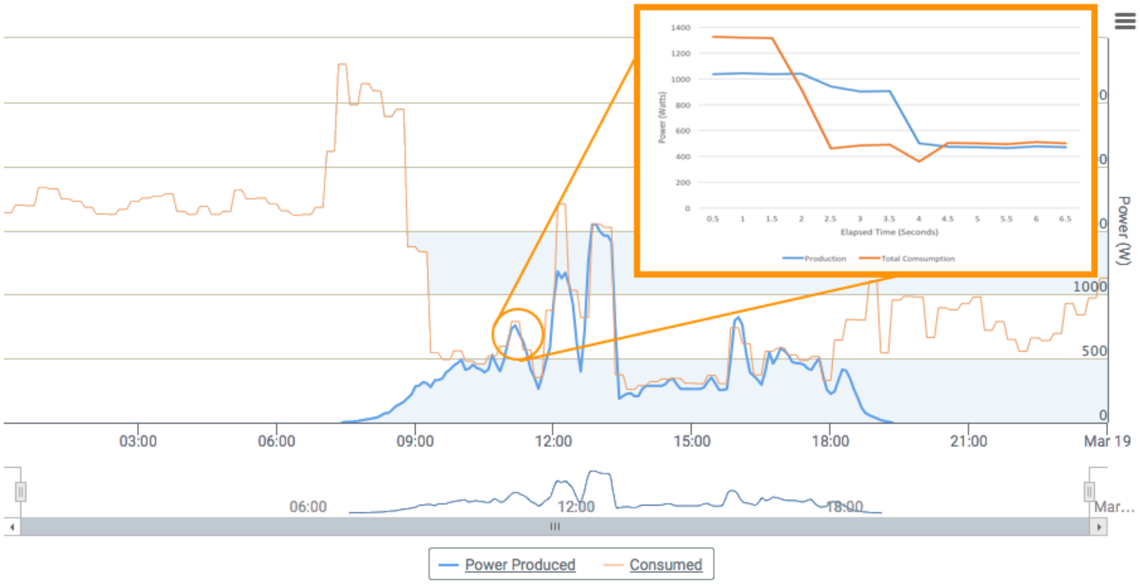
Also note that frequency / watt curtailment settings may be used on the IQ Microinverters if all microinverters are interconnected on the load side connection of the battery-based inverter system. In this scenario, the battery-based inverter system must be set to comply with the local interconnection frequency settings and isolate the microinverters from the grid according to these.

Power Export Limiting

For systems interconnected to a utility service that requires an export limit, the PV system must limit the amount of power exported to the utility grid. This means that any PV generation, not consumed locally by loads and exported onto the grid, must be limited as defined by the utility interconnection agreement. This export limit could be zero, meaning no power is allowed to be exported, or a set power value, e.g., 5 kW or 10 kW.

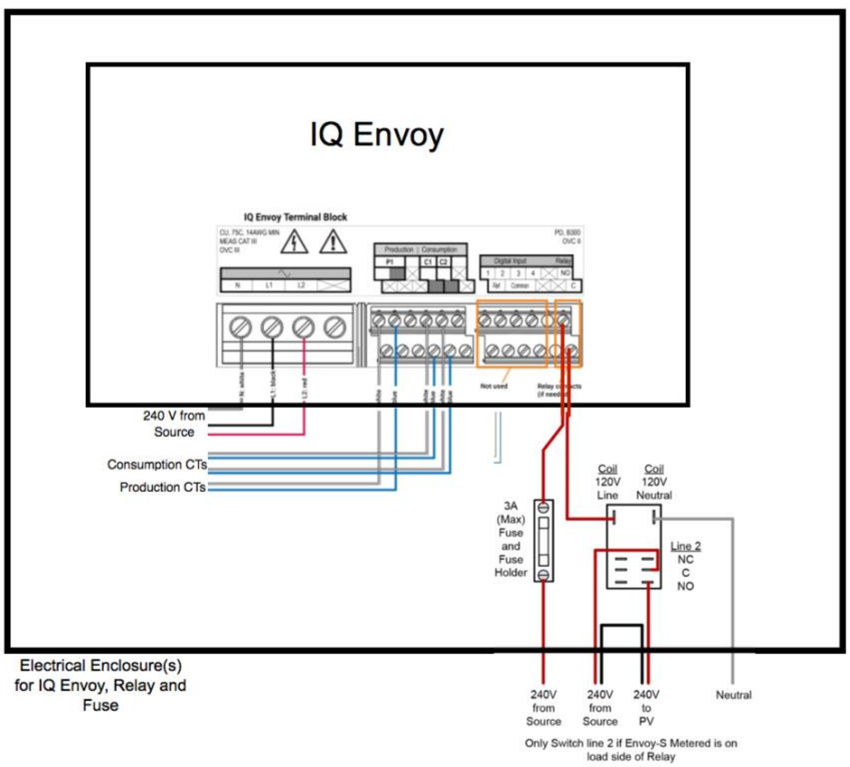
For example, let's take an 8 kW AC rated PV system that is operating at full output. If an export limit of 5 kW AC is required, and the loads in the building are only consuming 1.5 kW AC at a given time, the PV system must reduce its power output to 6.5 kW AC (8 - 1.5). The solution is for the PV system to measure the loads in the home via consumption metering and to limit the PV system exported power when needed. This functionality increases system sizes and provides a much better value to the customer.

This export limit function is part of the Enphase Energy IQ system. To enable export power limiting, an IQ Envoy is equipped and installed with production metering and consumption metering. The IQ Envoy, based on the consumption meter and production meter data, calculates whether any PV generation above the set export limit is exporting to the grid. Then it automatically sends power curtailment commands to the microinverters via the powerline. No external communications equipment needs to be installed. Pulling data from the consumption meter every 500ms and making adjustments to microinverter output at 1.5s intervals, an IQ Envoy constantly reacts to power export limits in two to four seconds. Microinverter power output increases also occur in the same amount of time. This functionality is set through the grid profile and called Export Limit – Soft Limit.



Example: Power export limiting - two second response time

Some systems may require a secondary protection circuit in case the control function of the export limit fails. In that case, the normally opened contact within the IQ Envoy can drive a contactor to provide this secondary level of protection. If the IQ Envoy loses power, the external contactor opens and disconnects the AC source to the IQ Microinverters.



The following settings define the IQ Microinverter system **Power Export Limiting**

- Export limit – Soft limit threshold in watts (min 0, max 30,000) – primary IQ Envoy control function
- Export limit – Hard limit (enabled / disabled) – optional secondary protection via external contactor
    - Communication loss time limit in milliseconds (min 30,000, max 120,000)
    - Hard limit threshold in watts (min 0, max 30,000)
    - Hard limit response time in milliseconds (min 10,000, max 60,000)

Exception: Microinverter systems set to <u>zero power export limit</u> may not produce power when AC coupled to third-party storage solutions to charge batteries. Until further notice we recommend to only AC couple microinverters when they have a total system power export limit greater than 100 W.

Load Considerations

Net Energy Metering – Load Considerations

Designing **utility interactive** NEM systems requires understanding annual energy consumption to determine the PV system size for maximum energy bill offset.

Adding **backup** to a utility interactive NEM system requires a backup or stand-alone loads analysis. This includes identifying the desired stand-alone loads' instantaneous power and desired backup period energy consumption to define the energy storage system capacity in watt-hours and battery-based inverter peak power output rating. Refer to design guidance provided by the manufacturer of the particular third-party storage system being used.

Export Limiting – Load Considerations

Utility interactive systems with export limits require an analysis of the annual energy consumption and daily load profile to determine PV system size for self-consumption. You can size an optional energy storage system based on the daily load profile to increase self-consumption of the PV system energy production.

Adding backup to a utility interactive system with export limits also requires a backup or stand-alone loads analysis. Refer to design guidance provided by the manufacturer of the particular third-party storage system being used.

Microgrid – Load Considerations

Microgrids often contain power generation resources that are not battery- or PV-based. Designing microgrids requires a much more comprehensive load study to determine the capacities and system sizes of different power generation and energy storage resources. This document does not detail microgrid design.

AC Coupling Safety and Design Considerations

In all battery-based systems, there are requirements for safe and reliable operation. Additional safeguards when AC coupling Enphase Microinverter systems include:

- Do not allow the batteries to overcharge. Overcharging batteries can damage the batteries and can potentially cause fires and catastrophic meltdowns. It is smart to provide redundant methods to regulate the charge to the battery.
- Do not connect the Enphase Microinverters to the output of an engine generator without properly designed protection and transfer equipment. This can cause damage to the microinverters and the generator.
- Design the Enphase Microinverter system so that it does not exceed the pass-through capabilities of the battery-based inverter's charging system.

Whenever working with batteries, take precautions to ensure safety. This is particularly true for AC coupled systems because traditional inverter chargers and charge controllers are not designed to regulate the charge from an AC coupled system. Therefore, take precautions to ensure that the batteries are not overcharged. Use one of the PV system curtailment options described above.

For additional battery protection, use a dump load to drain excess power out of the batteries in the case of overcharging. Do this by using some of the stored power to heat water or air with a listed and approved heating element.

If an engine generator is present, do not connect the Enphase Microinverters to the same load panel as the generator without properly designed protection and transfer equipment. When using a generator to charge batteries in a battery-based inverter system, the battery-based inverter also internally bypasses the generator's output to the back-up / emergency load panel that the Enphase Microinverters are feeding. Allowing this connection can damage the generator and microinverters. Therefore, if using a generator to charge batteries, ensure that the Enphase Microinverters are shut off when the generator is running. The best method is to use a voltage-controlled relay activated by the generator panel. Use a transfer switch to ensure that the generator is always isolated from the Enphase Microinverters.

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