



Application Note

DC Loading of PV Powered Inverters

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Introduction

The intent of this application note is to discuss the optimal DC loading of PV Powered inverters. Inverter loading is typically given as the array to inverter ratio. This is the ratio of the DC nameplate power rating of the photovoltaic array at Standard Test Conditions¹ (STC) to the AC nameplate output power rating of the inverter. It is typically given as a percentage.

$$\text{Array to Inverter Ratio} = \frac{\text{Array STC Power Rating}}{\text{Inverter Nameplate Rating}}$$

For example, if a 58kW DC photovoltaic array were connected to a PV Powered 50kW inverter, the array to inverter ratio would be:

$$58\text{kW} / 50\text{kW} = 116\%$$

Similarly, a 60kW array on the same 50kW inverter would give a ratio of 120%.

There are two common questions regarding the array to inverter ratio.

1. What happens if the array to inverter ratio is greater the 100%? For example, what happens if the array is larger than the inverter?
2. What is the optimal array to inverter ratio?

¹ STC is the standard conditions used to rate photovoltaic modules. STC is given by:

Irradiance=1,000 W/m²
Cell Temperature=25°C
1.5 Air Mass

Effect of 'Overloading' a PV Powered Inverter

In most cases, a system designer chooses an array to inverter ratio that is greater than 100%. This means that the DC-STC rating of the array is greater than the AC output rating of the inverter. Some of the reasons behind this are covered in the following section.

Overloading does not adversely affect PV Powered inverters. If the power available from the array exceeds the nameplate rating of the inverter, the inverter will limit the power and current coming from the array to the inverter's maximum nameplate power and current rating. The inverter does this by reducing the DC input current, which causes the DC operating voltage to rise above the maximum power point of the array, thereby 'clipping' the array output. This effectively limits the output of the array without stressing the inverter. It is important to note that this statement does not hold true for all inverter manufacturers. Some non-PV Powered inverters will not self limit. They will convert all the power available from the array and may be damaged by overloading.

The PV Powered inverter warranty is not affected by the DC loading used. PV Powered inverters are designed to operate at full-rated power indefinitely, even at the maximum allowed operating temperature. Reasonable overloading of a PV Powered inverter does not affect the inverter's warranty. The only risk is that energy will be lost due to the clipping action of the inverter.

There is a limit of allowed overloading which is determined by the maximum array short circuit current (Isc) rating of the inverter. The array maximum current as calculated per NEC 690.8(A)(2) must not exceed the inverter maximum array Isc. The maximum array Isc allowed for PV Powered commercial inverters are provided in the table below. These ratings are based on the current ratings of the components

used in the DC power path. In practical terms, this maximum array Isc limits the array to inverter ratio. The exact limit depends on the system design. Typically it is greater than 175%.

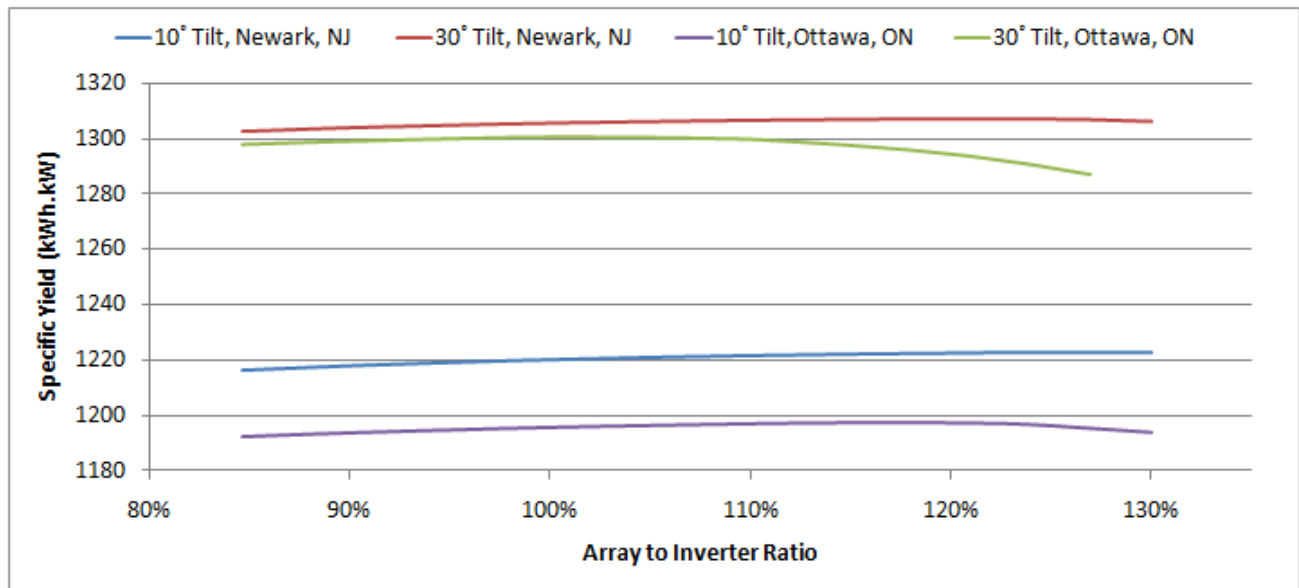
Inverter	Maximum Array Isc ²
PVP30kW	125A
PVP35kW	225A
PVP50kW	350A
PVP75kW	675A
PVP100kW	675A
PVP260kW	1600A

Optimal Array to Inverter Ratio

Optimizing the array to inverter ratio maximizes the quantity of energy the inverter will harvest from the photovoltaic array while minimizing inverter cost. This energy harvest is typically described as the Specific Yield, given in kWh/kW. This is a standardized measure of how much energy (kWh) each kilowatt (kW) of photovoltaic modules in the array will produce in a typical year.

Frequently the optimal array to inverter ratio is greater than 100%. The typical range is of array to inverter ratios is 115% to 125%, although a ratio as low as 80% or above 130% may make sense for a given design. An extremely oversized array may lead to the inverter clipping the array output much of the time. A wildly undersized array may lead to the inverter turning on later in the day and spend more time operating at a less efficient point in its power curve. However, because

² The sum of the ratings of the overcurrent devices feeding power to the inverter DC bus bars, whether internal or external to the inverter, must not exceed the values listed in the table. If no overcurrent devices are used, per the exception in NEC 690.9(A), then the available maximum current calculated per NEC 690.8(A)(2) must not exceed the values listed in the table below.



PV Powered inverters have a relatively flat efficiency curve the inverter operates at high efficiency over a wide range of power levels. Consequently, a wide range of array to inverter ratios will give good performance.

The optimal array to inverter ratio is a function of several things. Some of the factors include the local climate, the array tilt angle and orientation, the module technology used and the module mounting method used. As stated above, usually the optimal array to inverter ratio is greater than 100%. There are several reasons for this. Foremost, the Standard Test Conditions (STC) used for module ratings are conditions that rarely occur in real world installations. When the irradiance is high enough that the photovoltaic array supplies its full rated current, the ambient temperature is also usually high so that the operating voltage of the array drops below its value at STC. Similarly, when the temperature is cold and the array is operating at its STC maximum power voltage, the sun is typically at a low angle in the sky, not at an optimal angle perpendicular to the array, so the array cannot produce its full rated current. In addition, any soiling will decrease the array performance. Also, the photovoltaic modules themselves will degrade at a rate of 0.5% to 1% per year, so an array power

initially matched to the inverter power will drop below the inverter power as the system ages.

In general a higher array to inverter ratio is warranted for systems where the installation details will cause the array to operate frequently at a high temperature or, otherwise not experience peak power. This includes systems installed in hot climates, systems with flush mounted arrays or arrays at a low tilt angle. On the other hand, installations in cool climates, at a high tilt angle, on ground mounted structures, or using thin film modules, may benefit from a lower array to inverter ratio.

The chart above shows specific yield as a function of array to inverter ratio for four different combinations of climate and tilt angle.

The data used in the chart are from simulations of different sized crystalline array on a PV Powered 100kW inverter. The simulations were run for Ottawa, Ontario, and Newark, NJ at 10° and 30° tilts. This provides data in both cold and warm climates for both high and low tilt angle.

The most important conclusion that could be drawn from the above chart is that the effect of tilt angle and installation location on system performance/yield is much stronger than the effect of array to inverter ratio. The change in specific

yield is relatively small as the inverter loading is varied from 85% to 130%. Looking more closely we see that as expected, the optimal array to inverter ratio is the highest for the 10° Tilt, Newark, NJ system, which is installed in a relatively high temperature environment at a low tilt angle. The optimal array to inverter ratio is the lowest for the 30° Tilt, Ottawa, ON system, which is installed in a cold environment at a high tilt angle.

The 30° Tilt, Ottawa, ON does show that at higher inverter loadings the inverter is clipping the array output and limiting system performance. In a case like this, a cost-benefit analysis can determine whether a larger inverter is warranted to capture all the energy available from the array. How does the cost of the next larger inverter compare with the value of additional energy produced? In the end, the final decision on array to inverter ratio may come down to how much space is available for the photovoltaic array and what inverter sizes are available. Using system modeling similar to the example above is the best way to make an informed decision for your system.

Caution – DC Overvoltage

Note that all the above discussion applies to the array *power* connected to the inverter. Applying a DC input voltage above the inverter's maximum input is strongly discouraged. It is the installer's responsibility to ensure that the array voltage remains below the specific maximum input voltage. Damage caused by an overvoltage will not be covered under warranty.



All PV Powered products are designed and manufactured in the U.S., are fully compliant with the Buy American Act, and qualify for projects funded by the federal stimulus package.