

Supersize It

How oversizing your array-to-inverter ratio can improve solar-power system performance

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PV system designers are tasked with the important decision of selecting the optimal array-to-inverter ratio for each inverter in a project. The array-to-inverter ratio defines the relationship between the array's nameplate power rating at Standard Test Conditions to the inverter's rated AC output. As an example, a system with a 120-kWdc array feeding a 100-kWac inverter has an Array-to-Inverter Ratio of 1:2. Until recent years, due to the high cost of modules, PV systems were designed to maximize energy production per PV module. This approach typically resulted in oversizing ratios between 1:10 to 1:25, depending on the project location and design specific DC loss factors such as tilt angle, orientation, mounting method, DC wiring losses, mismatch and soiling. With falling module prices, project financials have changed in favor of higher array-to-inverter ratios. It's important to understand why systems are being oversized, the technical considerations relating to oversizing and the impact of oversizing on inverter life.

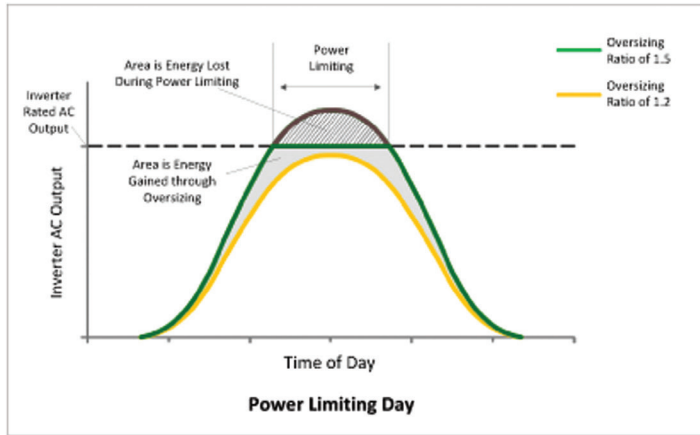


Figure 1a: Daily Production Profile Power Limiting Day

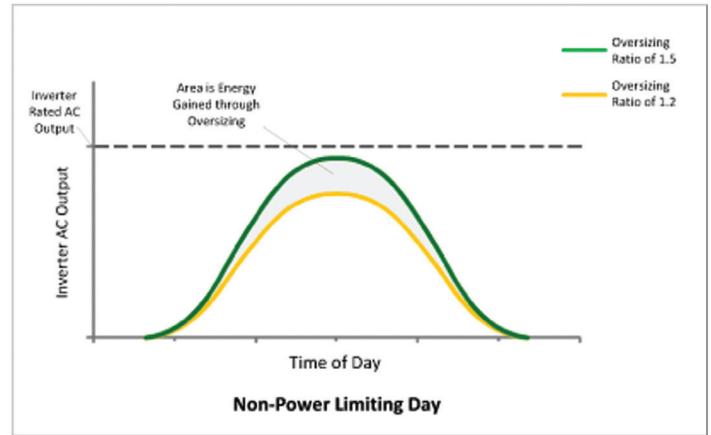


Figure 1b: Daily Production Profile Non-Power Limiting Day

Why Should You Oversize

Just a few short years ago, the main driver of system design was the high cost of PV modules. The goal of designers was to ensure maximum energy harvest from each module in the system. By doing so, designers ensured the optimal use of this high-cost system component. Best design practices were to place modules to avoid shading from obstructions and between racking rows, and to size the array to the largest capacity so the inverter spent little to no time power limiting. Power limiting is an inverter function that occurs when the available power from the array is greater than the inverter’s rated input power. Power limiting is often called “clipping” due to the flattening effect on the system’s daily production profile, as shown in **Figure 1a** and **1b**.

During power limiting, the inverter controls the input power from the array by shifting the array’s operating point to a higher-voltage and lower-current operating point along the array’s current-voltage (I-V) curve, thereby deviating from the maximum power point of the array. This is shown in **Figure 2**.

By maximizing production per module, designers achieve the optimal specific yield of the system. Specific yield is the system’s annual energy harvest per kW of installed DC capacity. Specific yield is expressed in units of annual kWh/kW. Optimizing specific

yield typically results in array-to-inverter ratios ranging from 1:10 to 1:25, depending on project location and DC derating factors.

With lower PV module prices, the incremental cost of adding additional DC capacity to a system has greatly decreased. Since a larger array feeding a fixed size inverter will result in greater system annual production, the increased annual energy harvest is spread across the system’s fixed/semi-fixed costs, which include inverters, AC collection system, permitting, interconnection fees, engineering and overhead. As a result, project financials have shifted in favor of increased Array-to-Inverter ratios. The scales tip even further in favor of oversizing when considering time-of-use (TOU) utility rate structures, which place the greatest monetary value for energy delivery in the afternoon during summer months. Through oversizing, systems produce greater energy when energy has the greatest value.

Oversizing due to fixed vs. incremental cost effect and the TOU effect has manifested itself in different ways throughout the industry. Increased oversizing is now being seen in large-scale utility projects in the desert Southwest, with oversizing ratios more than 1:5, as well as in space constrained commercial rooftop installations, where designers have begun encroaching into shaded regions of the roof. Commercial and

utility systems alike are exploring the effects of reducing module tilt angle, decreasing inter-row separation and reducing module-cleaning schedules, all factors that result in non-optimal specific yield — with the aim of gaining increased annual production — with the same fixed-cost structure.

To quantify the effects of oversizing, system designers perform an oversizing analysis using a PV system simulation program such as PVsyst, PV*SOL or SAM. To be suitable for oversizing analysis, the simulation program must be capable of modeling the power-limiting behavior of the inverter. Additionally, the program must be able to provide hourly data values when financial models are built on a time-of-use rate structures. In most cases, oversizing analysis is performed through successive simulations where the inverter size is kept constant while the array size is varied. The project team may also look at the effects of keeping the array size constant while varying the inverter kW rating. The end result is a dataset that shows the effects of array-to-inverter ratios on hourly and annual production.

The production values from the analysis are then fed into the financial model of the project to determine the optimal array-to-inverter ratio. The details of financial models will vary, but most have the same overall goal of optimizing a financial metric such as Levelized

Cost of Energy (LCOE), Net Present Value (NPV), or Internal Rate of Return (IRR). An example oversizing financial analysis is shown in **Figure 3** (see next page). The analysis shows that oversizing improves the economics of a project up to a certain point; beyond that point, however, the project begins experiencing diminishing returns.

What Factors Limit Oversizing

Oversizing exposes the inverter to the following:

- Increased available power from the array
- Increased available short-circuit current from the array
- Slightly increased full-power input voltage during power limiting
- Increased operational hours at full power

Discussions up to this point have assumed that the inverter has power-limiting capability, which is true of UL1741-listed inverters. As part of listing to UL1741, an “Output Overload Test” is performed to confirm the inverter’s ability to maintain rated output power when

fed by a DC source equal to twice the inverter-rated input current.

Although the inverter has the ability to control the current from the array during normal power-conversion operation, during a DC-side fault, the inverter’s capability to control the current from the array is through interruption at best. The scenario that subjects the inverter to the highest short-circuit current is a low-impedance fault (“bolted fault”) within the inverter’s DC section between the ungrounded and grounded circuitry, or between ungrounded circuitry and ground. During these scenarios, the inverter is exposed to the full short-circuit current of the array. The inverter’s DC side components, including bus bars, cables and switches, must be rated to carry and interrupt (in the case of electromechanical switches) the array’s available short-circuit current. The weakest link in this circuit dictates the maximum short-circuit current that the inverter is rated to handle. Based upon the desired string count and string size, the maximum Array-to-Inverter ratio can then be determined.

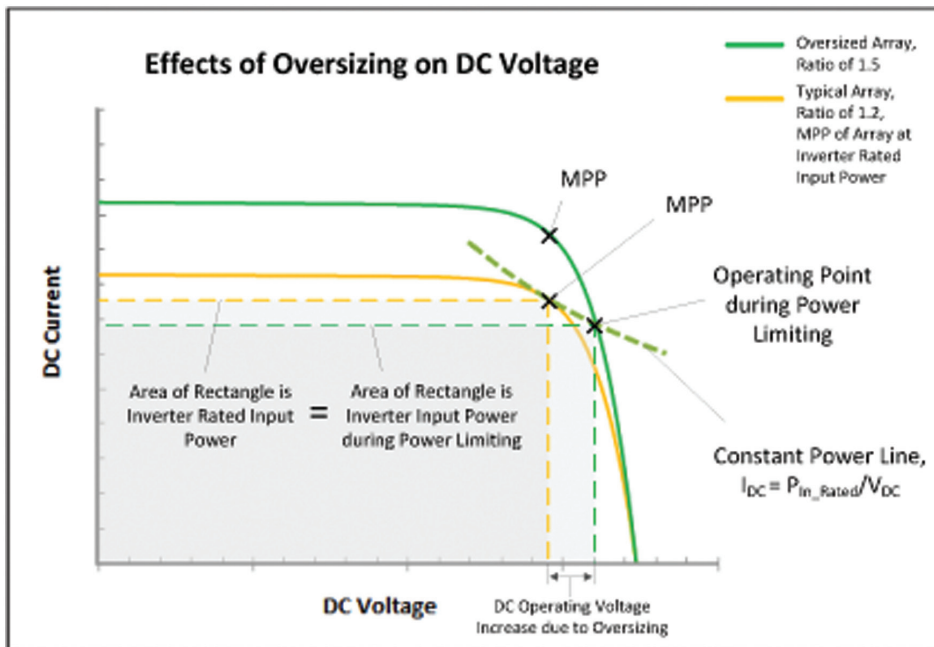


Figure 2: Array I-V Curves And Operating Points Of Typical And Oversized Arrays

Effect Of Oversizing On Inverter Life

Designers, developers and system owners should view the effects of oversizing on inverter life and Mean-Time-Between Failure (MTBF) through practical lenses. Large array-to-inverter ratios cause the inverter to work harder for longer hours. In addition, most commercial three-phase inverters operate less efficiently when operating above the maximum power point voltage, resulting in greater internal-heat rejection. Common sense tells us that this can cause some of the temperature-sensitive components to age faster compared to a lightly-loaded scenario.

The good news is that inverters have thermal-management architectures to control internal temperatures to protect the inverter during prolonged periods of full-power operations. These measures also act to help preserve the life of temperature sensitive components. Inverters sense temperatures of critical components and have programmed set points that trigger increased blower fan speed and power limiting as means of regulating internal temperature.

In addition, inverters have critical temperature limits that, once reached, result in inverter shutdown. Inverters also include one or more temperature switches as a backup safety mechanisms in the event of an uncontrolled temperature increase due to failures in the inverter's thermal-management-control systems. System designers should understand the inverter's maximum ambient operating temperature for full-rated power and consider other factors that affect the inverter's operating temperature and cooling ability, including inverter shading, elevation and mounting location (indoor/outdoor, ventilated/conditioned). Designers are encouraged to use good engineering judgment and attempt to promote optimal cooling of the inverter to ensure the longest life of the equipment. System owners should perform regularly scheduled maintenance of any air intake filters and cooling system.

What About The Warranty?

Discussions of inverter life and MTBF lead to perhaps the biggest question from designers, developers and EPCs regarding oversizing: "How will oversizing affect my inverter warranty?" It is recommended to work closely with your inverter provider to understand how oversizing effects warranty and related offerings, such as preventative maintenance plans and uptime-guarantees.

What's Best — And What's Next

What is the best oversizing ratio? The answer should now be apparent: It depends. Factors to consider include project location, design specifics, project-cost structure, financial model and other project goals.

How will oversizing practices change in the future? With the continued downward trend of module prices and the potential for an increasing number of utilities transitioning to time-of-use rate structures, combined with future technology to capture energy lost during power limiting or to temporarily overdrive inverters for grid support, indications are that the practice of oversizing only stands to continue. **SPW**

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Figure 3: Example Oversizing Financial Analysis

