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Renewables Insights

The Impact of Solar Photovoltaics (PV) DC:AC Ratio

In recent years, solar project developers have continued to increase the dc:ac ratio[1] (also known as inverter loading ratio) of their PV plants by installing extra PV modules such that the cumulative dc nameplate capacity of the plant exceeds the cumulative ac nameplate capacity of the inverters. This design approach has been driven by a desire to maximize energy production combined with rapidly falling PV module costs, making the economics favorable. According to Lawrence Berkeley National Laboratory's Utility-Scale Solar 2016 report, between 2010 and 2016, the average dc:ac ratio of a utility-scale PV project increased from below 1.2 to more than 1.3.

Increasing the dc:ac ratio of a solar plant has both pros and cons from an operational perspective. On the positive side, the plant will see increased energy yield for a given inverter size (kWh/kW) with the ability to produce additional electricity during the morning and evening, as well as on cloudy days or winter months, as illustrated in Figure 1. The plant also sees relatively less variable power generation because it is able to produce at maximum ac output more frequently. However, there are still open research questions about the impact of dc:ac ratios over one on equipment reliability. During times of energy clipping, the inverter makes the modules run less efficiently, meaning they run at hotter temperatures and may degrade faster. Also, it is not known how wear-out differs when inverters run at full power output during times of clipped energy versus temperature cycling due to variable irradiance.

Key Takeaway

Increasing a PV plant's dc:ac ratio increases energy output for a plant of a given MWac capacity. However, the marginal additional energy output decreases with increasing dc:ac ratio due to an increased amount of clipped energy at higher ratios

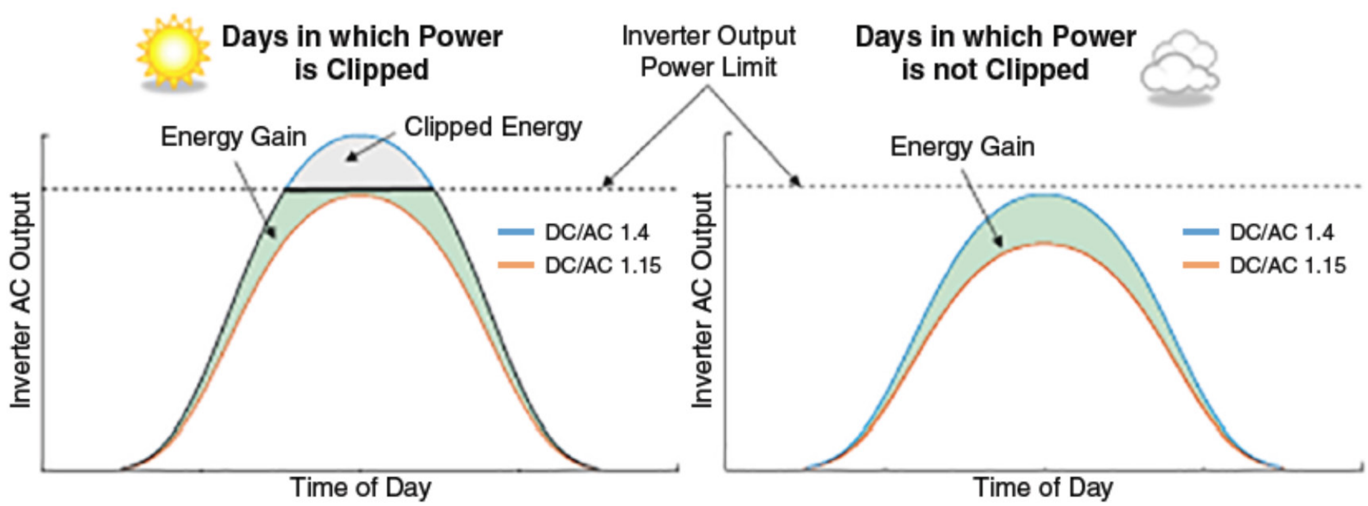

Figure 1: Energy gains from increased dc:ac ratio

1. dc:ac ratio is the dc nameplate power of a PV plant (i.e., cumulative nameplate of all PV modules) divided by the ac nameplate of the plant (i.e., cumulative nameplate of all inverters). For example, a dc:ac ratio of 1.3 means there is 30% more module nameplate capacity than inverter capacity.

There are also economic tradeoffs as the dc:ac ratio increases. When evaluating the levelized cost of energy (LCOE) of a PV plant, an increase in the annual energy production of the PV plant means that there are more kWh over which the capital cost of the plant are spread. If the incremental cost of additional PV modules and associated balance of plant and operating expenses are less than the incremental additional output, then the LCOE can decline with increasing dc:ac ratio. However, there is declining marginal value as the dc:ac ratio continues to increase and the amount of clipped energy also increases.

An illustrative high-level analysis demonstrates these tradeoffs. Using the System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL), the energy output and LCOE were calculated for a range of dc:ac ratios for a PV plant at three locations representing high, average, and low solar insolation in the United States: Daggett, CA; Kansas City, MO; and Seattle, WA, respectively. As shown in Figures 2 and 3, energy production increases with increasing dc:ac ratio, though the incremental increase declines with higher dc:ac ratios. The LCOE of the plant initially decreases slightly as the dc:ac ratio increases beyond one due to the increased energy production. However, for this series of assumptions, beyond a dc:ac ratio of 1.15 to 1.2, the LCOE begins to increase due to the increase in clipped energy preventing the increase in energy production from fully offsetting the required additional capital cost for additional PV modules.

Fixed-Tilt PV Plant

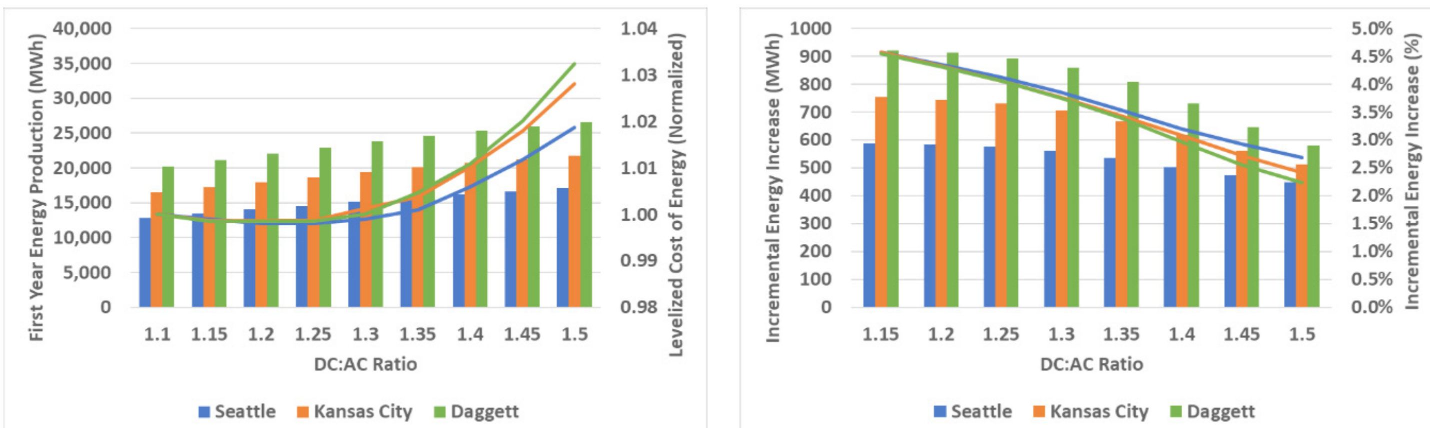

Figure 2: Illustrative example: Impact of dc:ac ratio on first year energy production (left chart, bars), normalized LCOE (left chart, lines), and incremental energy output in MWh (right chart, bars) and percentage (right chart, lines) for a fixed-tilt PV plant

Single-Axis Tracking PV Plant

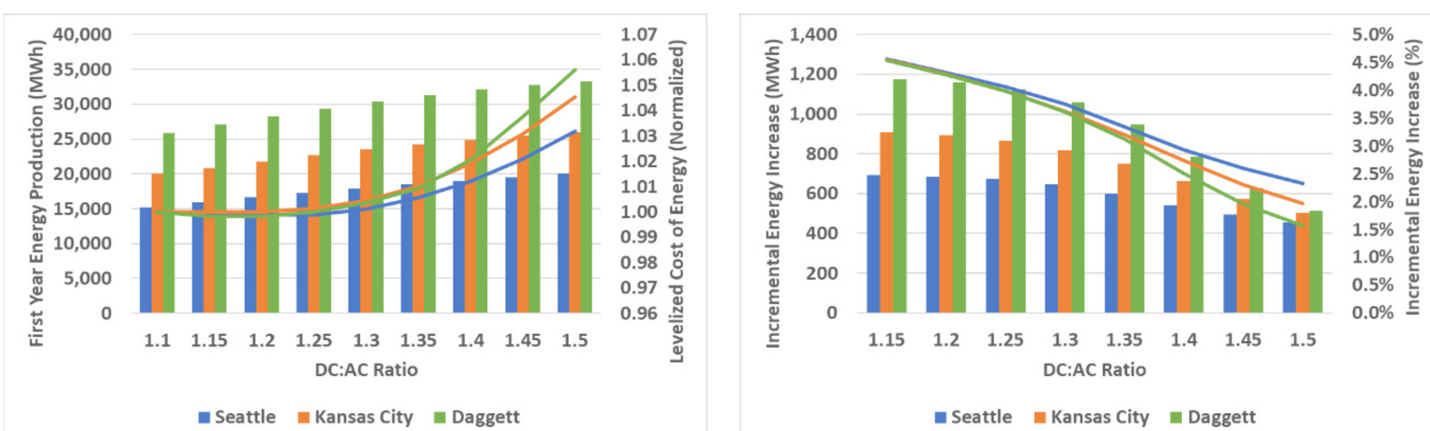

Figure 3: Illustrative example: Impact of dc:ac ratio on first year energy production (left chart, bars), normalized LCOE (left chart, lines), and incremental energy output in MWh (right chart, bars) and percentage (right chart, lines) for a single-axis tracking PV plant

While this analysis illustrates at a high level some of the tradeoffs in dc:ac ratio, when actually planning and designing a plant, a much more sophisticated analysis is required to determine the optimum ratio for the particular plant conditions. Several additional factors must be considered, such as site-specific weather data, local soiling analysis, power block layout with respect to land constraints, and module and plant power degradation considerations impacted by the operating profile of the plant. Additionally, transmission and interconnection concerns and financial incentives and penalties may cause a project developer to select a dc:ac ratio that differs from the one that would minimize LCOE.

ASSUMPTIONS AND RESOURCES

- Simulations run using NREL SAM version 2017.9.5. SAM can be downloaded for free from https://sam.nrel.gov/.
- PV cost data taken from Fu R, et. al. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017*. NREL Technical Report. August 2017. https://www.nrel.gov/docs/fy17osti/68925.pdf
- Average inverter loading ratio from M. Bolinger, et al. *Utility-Scale Solar 2016: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/utility-scale-solar-2016-report.pdf
- California Corporate Tax Rate: https://www.ftb.ca.gov/businesses/faq/717.shtml
- California Sales Tax Rate: https://www.cdtfa.ca.gov/taxes-and-fees/sales-use-tax-rates.htm
- Missouri Corporate Tax Rate: https://dor.mo.gov/business/corporate/
- Missouri Sales Tax Rate: https://dor.mo.gov/business/sales/rates/
- Washington State Corporate Tax Rate: No corporate income tax; there is a utility tax that the final distributor of the power is responsible for that is not captured in this analysis
- Washington State Sales Tax Rate: https://dor.wa.gov/find-taxes-rates/retail-sales-tax

System Cost – Fixed Tilt ($/Wdc)[2]	1.25-1.28
System Cost – Single-Axis Tracking ($/Wdc)[2]	1.37-1.40
Plant Size (MWac)[3]	10
Annual Degradation (%)	0.75%
O&M Expenses ($/kW-yr)	15.40
Inverter Efficiency (%)	98.0%
Equity Discount Rate (real)	6.3%
Inflation Rate	2.5%
Debt Interest Rate	4.5%
Debt Fraction	40%

2. System costs for each case are slightly different solely due to the difference in sales tax rate in each state. In actuality, a host of factors such as land cost, prevailing labor rates, transportation costs, etc. would lead to greater variation in system cost for the locations chosen.

3. System sized to output 10MWac at all dc:ac ratios

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