Why Is My PV Module Rating Larger Than My Inverter Rating?

PV module and inverter selection are two of the most important decisions in PV system design. Ensuring that these components will work together is important from a technical, reliability, and economic perspective. Goals and design assumptions of different stakeholders can influence the decision-making process. The following considerations may ease the decision-making process:

- The DC: AC ratio is the relationship between PV module power rating and inverter power. Every PV system has a DC:AC ratio regardless of architecture. Many inverters have DC:AC ratio limitations for reliability and warranty purposes. **Enphase Microinverters have no DC:AC ratio input limit aside from DC input voltage and current compatibility.**

- **Higher DC:AC ratios always improve inverter utilization and the capacity factor.** The measurement of inverter utilization is capacity factor—the ratio between actual and maximum energy production. A significant portion of system cost is tied to the AC rating of the inverter (string or microinverter). Installing more DC on a given inverter will increase the capacity factor and may drive down the overall dollar per watt system cost.

- DC losses in string inverter systems (including those with optimizers) are typically higher than in microinverter systems. This means that string inverter system simulations may show lower clipping losses at a given DC:AC ratio. However, these additional DC losses also impact the nominal DC:AC ratio and result in better nominal DC:AC ratios for microinverters systems for a given pairing.

- Clipping losses in systems are typically very low compared to other sources of losses, such as orientation factors, soiling, shading, and thermal losses. Additionally, clipping losses over time decrease as modules degradation takes place, while other loss factors such as soiling and shading generally increase.

- Economic implications of various system performance metrics, including better inverter utilization and capacity factor by designing with higher DC:AC ratios, are ultimately dependent on the economics of the local energy market and system installation configuration. Economic simulation tools such as NREL SAM[1] allow stakeholders to make their own evaluations.

Background

Why is my PV module rating larger than my inverter rating? — This common question has a simple answer. In real world conditions, PV module output rarely produces power at the rated output due to thermal losses. PV module power is a product of DC current and DC voltage. In a PV module, the DC voltage is a function of PV module cell temperature. That is, DC voltage goes down as cell temperature goes up. DC current is a function of the amount of available sunlight, called irradiance, which depends on the position of the sun relative to the module orientation and to environmental conditions.

[1] System Advisor Model. National Research Energy Laboratory. Golden, CO. https://sam.nrel.gov/content/downloads.

Figure 1 shows the DC measurements of a PV module over time. Most of the time, the PV module output power is well below the DC input limit (blue slanted line). When the input power limit is reached, the inverter raises DC input voltage to limit the AC power output to the peak output power rating of the microinverter model. This state is known as power clipping. If the DC input limit is never reached, the inverter never clips and is underutilized.

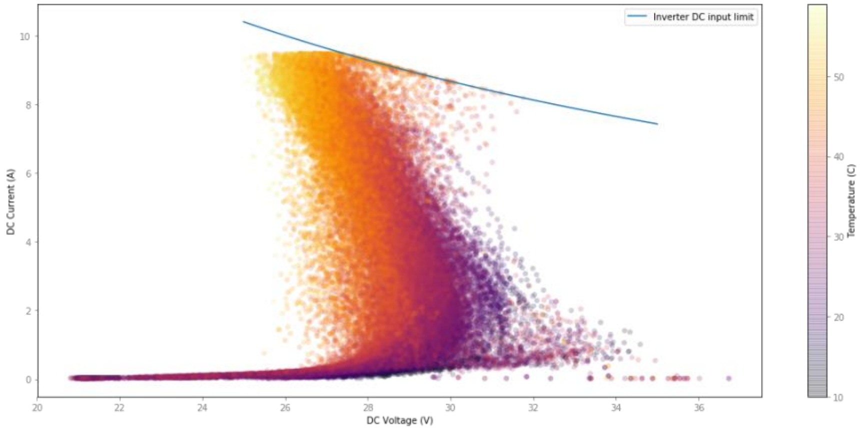

Figure 1: Example 5-minute data showing DC power input of an Enphase Microinverter

The measurement of inverter utilization is known as capacity factor and is defined as the ratio between actual and maximum energy production (think of the inverter running at full output all the time, it would have a capacity factor of 1.0). A higher capacity factor indicates higher use of inverter rated capacity. *Figure 2* identifies how capacity factor increases with higher DC:AC ratios and shows the effects of module orientation.

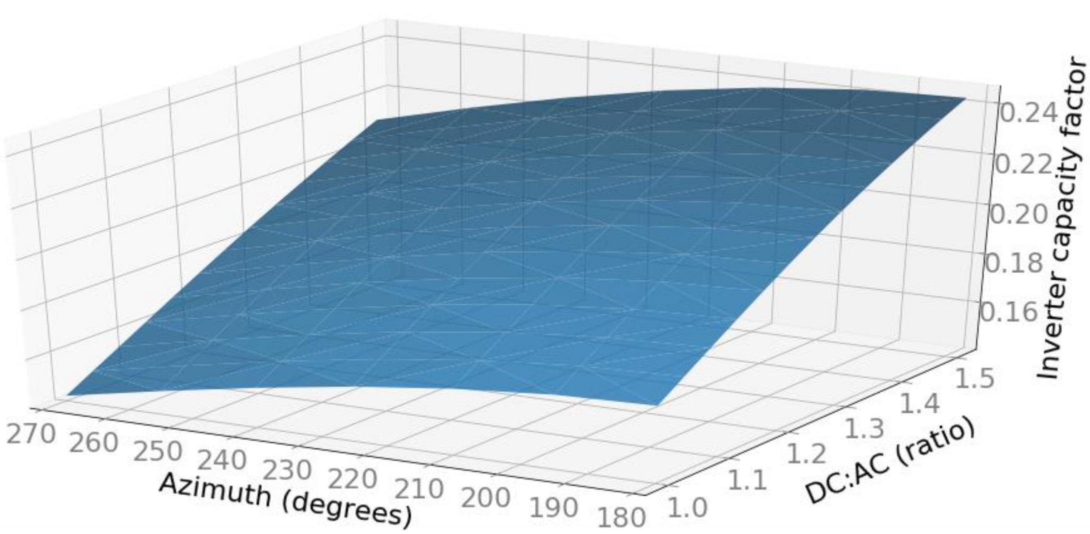

Figure 2: Newark - Simulated capacity factor 25º tilt

Inverter capacity factor and PV module clipping are two of the many performance metrics to consider when evaluating the design of a PV system. Asking “Why is my PV module rating larger than my inverter rating?” leads to a much more complicated question: “How much larger should my PV module be?”. Unfortunately, the answer to that question is not simple.

Theory

Sizing starts by ensuring that PV modules are electrically compatible with the inverter. Enphase provides an online module compatibility calculator to determine electrical compatibility, purely based on the inverter DC input voltage and current ranges: https://enphase.com/en-us/support/module-compatibility

The relationship between PV module power rating and inverter output power rating is often referred to as the DC: AC ratio:

$$\text{DC:AC ratio} = \frac{P_{STC}}{P_{MAX\ AC}}$$

Enphase Microinverters safely limit inverter power output electronically at the **peak output power** rating. Inverters are tested for reliability in these conditions, and microinverters have no contractual DC:AC ratio limitations.

There are some real-world factors that effectively reduce the DC:AC ratio. Calculating a Nominal DC:AC ratio can ease comparisons.

$$\text{Nominal DC:AC Ratio} = \frac{P_{DC}(1 - L_{total})\eta}{P_{AC\ MAX}\cos\theta}$$

Where: P_{DC} is DC power, L_{total} are total DC losses, η is the efficiency of the DC to AC conversion process independent of architecture, and θ is the phase angle between voltage and current. DC losses due to module orientation, module degradation, module mismatch, DC wiring, connections, soiling, and shading reduce available DC power and in turn, lower the Nominal DC:AC ratio. PVWatts, for example, uses a default suggested loss: L_{total} of 14%[2].

For example, the DC:AC ratio of a 300 Watt PV module on an IQ 6 inverter would be:

$$\text{DC:AC Ratio} = \frac{300\ DC\ W_{STC}}{240\ W_{peak}} = 1.25$$

However, with soiling and DC connection losses, it is reasonable to assume that an L_{total} of 5.6% paired with a 97% efficient inverter effectively reduces the DC:AC ratio, leading to a lower nominal DC:AC ratio:

$$\text{Nominal DC:AC ratio} = \frac{300\ DC\ W_{STC} * (1 - .056) * .97}{240\ W_{peak}\cos 0} = 1.14$$

Some architectures have a second DC:DC conversion stage. To calculate full DC to AC efficiency, it is necessary to multiply the DC:DC optimizer efficiency by the string inverter efficiency.

2

NREL. 2014. *PVWatts Version 5 Manual .* Technical Report, National Renewable Energy Laboratory, Golden: U.S. Department of Energy.

Determining the best DC:AC ratio is a mathematical optimization problem. Optimization problems attempt to find the best feasible solution given a set of assumptions, where best is some cost function. In the context of a solar energy system there are many cost functions, including:

- Maximize energy harvest,
- Maximize net present value (NPV),
- Minimize monthly bill,
- Minimize payback time,
- Minimize inverter clipping,
- Maximize system efficiency, or
- Maximize capacity factor

Limits that can affect the optimum choice include:

- Available roof space,
- Solar access due to shading,
- Solar access due to module orientation limitations,
- Electrical service rating,
- Utility and regulatory requirements,
- Available capital, or
- Available equipment

Combining multiple performance metrics is referred to as a multi-variate optimization problem. When making cost determinations, the entire system and installation process must be considered. It is important to note that the best solution for a specific system may not be the best solution for the region. This is known as the difference between the local and global optimum. Installers may use a simplified calculation to determine the economic value of lost energy relative to the cost of system components as one possible performance metric. Alternatively, an installer may make the determination that benefit from optimized system design does not outweigh the additional engineering costs passed on to the homeowner.

Example Simulations Looking at Energy Yield Performance

To provide some context on DC:AC ratios and assist in the decision-making process, energy performance was simulated with NREL System Advisor Model (SAM) using the *Polymer Sheet Open Rack Simple Efficiency Module Model* (temperature coefficient: -0.4%/°C Pmp) with TMY3 weather data. The L_{total} was 0.6%, unless otherwise noted. Soiling was assumed to be zero with 0.6% loss in the DC connections. These DC loss assumptions are very conservative. Real-world losses, such as soiling, can be higher, which in turn would decrease resulting clipping losses. There are many tools that perform similar calculations, though NREL SAM supports parametric simulations which helps given the large number of system configurations and locations in this simulation.

The charts provided are for Newark, but the observation principles are valid for other locations. *Figure 3* shows the energy yield disparity due to clipping as the azimuth and DC:AC ratio varies. As azimuths depart from ideal south facing orientation in the northern hemisphere, losses from clipping greatly diminish. However, so does total production.

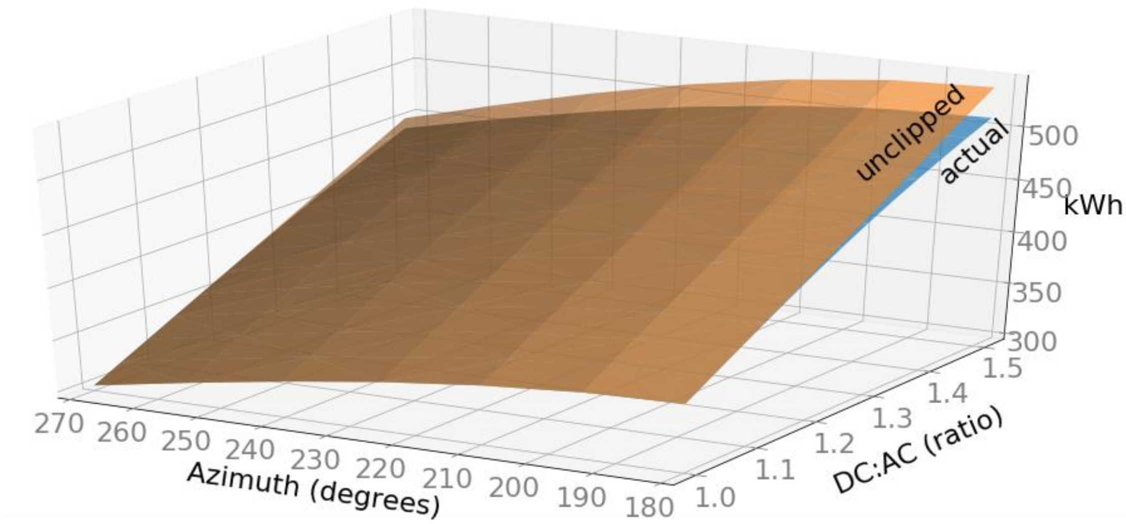

Figure 3: Newark - Simulated actual vs unclipped performance

As observed in *Figure 4*, increasing DC:AC ratio increases energy yield, however there may be some loss of energy harvest due to inverter clipping. The increased energy yield is always larger than the loss due to clipping, even at very high DC:AC ratios. Note that the inverter clipping shown is simulated first-year clipping. PV module power output degrades over time, so clipping losses will degrade proportionally.

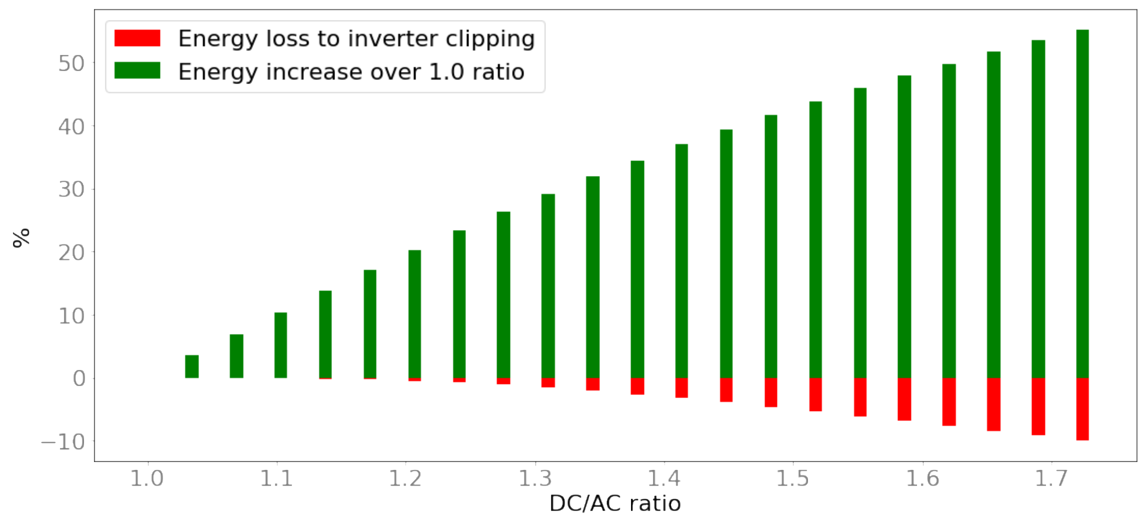

Figure 4: Newark 25° tilt 180° azimuth

IQ 6 Simulation Results

The following tables indicate example simulated single-module year-one inverter capacity factor, clipping and energy yield for various DC:AC ratios on the IQ 6 Microinverter in various US locations, using a -0.4%/C simple efficiency model. The IQ 6 Microinverter has a peak output power rating of 240 VA. In this model, the module orientation is fixed at 180° azimuth, 25° tilt, and L_{total} at 5.6%. Many real-world PV systems do not have ideal true south orientations of 180° azimuth and ideal tilt angles, so the impact of clipping will be less than shown in the tables below.

Table 1: **IQ 6** - Newark, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
240	1.00	0.92	0.156	329	0.0%	0.0	0%
250	1.04	0.96	0.163	343	0.0%	0.0	4%
260	1.08	1.00	0.170	357	0.0%	0.0	8%
270	1.12	1.03	0.176	370	0.0%	0.0	13%
280	1.17	1.07	0.183	384	0.0%	0.0	17%
290	1.21	1.11	0.189	398	0.0%	0.2	21%
300	1.25	1.15	0.196	412	0.1%	0.5	25%
310	1.29	1.19	0.202	425	0.2%	1.1	29%
320	1.33	1.23	0.208	438	0.4%	2.0	33%
330	1.38	1.26	0.214	450	0.7%	3.5	37%
340	1.42	1.30	0.220	462	1.1%	5.5	41%
350	1.46	1.34	0.225	473	1.6%	8.1	44%
360	1.50	1.38	0.230	484	2.2%	11.4	47%
370	1.54	1.42	0.235	494	2.8%	15.2	50%
380	1.58	1.46	0.240	504	3.5%	19.4	53%
390	1.62	1.49	0.244	513	4.3%	24.1	56%
400	1.67	1.53	0.248	522	5.1%	29.4	59%
410	1.71	1.57	0.252	530	5.9%	35.0	61%

Table 2: **IQ 6** - Denver (Golden), -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
240	1.00	0.92	0.179	376	0.0%	0.0	0%
250	1.04	0.96	0.186	392	0.0%	0.0	4%
260	1.08	1.00	0.194	407	0.0%	0.0	8%
270	1.12	1.03	0.201	423	0.0%	0.1	13%
280	1.17	1.07	0.209	439	0.1%	0.4	17%
290	1.21	1.11	0.216	454	0.2%	1.1	21%
300	1.25	1.15	0.223	468	0.5%	2.4	25%
310	1.29	1.19	0.229	482	0.9%	4.4	28%
320	1.33	1.23	0.235	495	1.4%	7.2	32%
330	1.38	1.26	0.241	507	2.0%	11.0	35%
340	1.42	1.30	0.247	518	2.8%	15.7	38%
350	1.46	1.34	0.251	529	3.7%	21.2	41%
360	1.50	1.38	0.256	539	4.6%	27.2	43%
370	1.54	1.42	0.261	548	5.5%	33.8	46%
380	1.58	1.46	0.265	557	6.5%	40.8	48%
390	1.62	1.49	0.269	565	7.5%	48.4	50%
400	1.67	1.53	0.273	573	8.6%	56.5	52%
410	1.71	1.57	0.276	580	9.6%	64.8	54%

Table 3: **IQ 6** - Los Angeles, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
240	1.00	0.92	0.191	402	0.0%	0.0	0%
250	1.04	0.96	0.199	419	0.0%	0.0	4%
260	1.08	1.00	0.207	436	0.0%	0.0	8%
270	1.12	1.03	0.216	453	0.0%	0.0	13%
280	1.17	1.07	0.224	470	0.0%	0.0	17%
290	1.21	1.11	0.232	487	0.0%	0.2	21%
300	1.25	1.15	0.239	503	0.1%	0.7	25%
310	1.29	1.19	0.247	518	0.4%	2.4	29%
320	1.33	1.23	0.253	533	0.9%	5.1	32%
330	1.38	1.26	0.260	546	1.6%	9.1	36%
340	1.42	1.30	0.265	558	2.3%	14.1	39%
350	1.46	1.34	0.271	569	3.2%	19.6	41%
360	1.50	1.38	0.276	580	4.1%	25.8	44%
370	1.54	1.42	0.281	590	5.0%	32.7	47%
380	1.58	1.46	0.285	599	6.0%	40.5	49%
390	1.62	1.49	0.289	608	7.1%	49.0	51%
400	1.67	1.53	0.293	616	8.2%	57.9	53%
410	1.71	1.57	0.297	624	9.3%	67.3	55%

Table 4: **IQ 6** - Phoenix, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
240	1.00	0.92	0.209	439	0.0%	0.0	0%
250	1.04	0.96	0.217	457	0.0%	0.0	4%
260	1.08	1.00	0.226	475	0.0%	0.0	8%
270	1.12	1.03	0.235	494	0.0%	0.0	13%
280	1.17	1.07	0.244	512	0.0%	0.0	17%
290	1.21	1.11	0.252	531	0.0%	0.1	21%
300	1.25	1.15	0.261	549	0.1%	0.3	25%
310	1.29	1.19	0.269	566	0.2%	1.1	29%
320	1.33	1.23	0.277	583	0.4%	2.7	33%
330	1.38	1.26	0.285	599	0.9%	5.7	37%
340	1.42	1.30	0.291	612	1.6%	10.4	40%
350	1.46	1.34	0.297	625	2.4%	16.5	42%
360	1.50	1.38	0.303	636	3.4%	23.7	45%
370	1.54	1.42	0.308	647	4.5%	31.9	47%
380	1.58	1.46	0.312	656	5.6%	40.9	50%
390	1.62	1.49	0.316	665	6.7%	50.4	52%
400	1.67	1.53	0.320	674	7.9%	60.5	54%
410	1.71	1.57	0.324	682	9.0%	71.0	55%

IQ 6+ Simulation Results

The following tables indicate example simulated single-module year-one inverter capacity factor, clipping and energy yield for various DC:AC ratios on the IQ 6+ Microinverter in various US locations, using a -0.4%/C simple efficiency model. The IQ 6+ Microinverter has a peak output power rating of 290 VA. In this model, the module orientation is fixed at 180° azimuth, 25° tilt, and L_{total} at 5.6%. Many real-world PV systems do not have ideal true south orientations of 180° azimuth and ideal tilt angles, so the impact of clipping will be less than shown in the tables below.

Table 5: **IQ 6+** - Newark, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
290	1.00	0.92	0.189	398	0.0%	0.0	0%
300	1.03	0.95	0.196	412	0.0%	0.0	3%
310	1.07	0.98	0.202	426	0.0%	0.0	7%
320	1.10	1.01	0.209	440	0.0%	0.0	10%
330	1.14	1.05	0.216	453	0.0%	0.0	14%
340	1.17	1.08	0.222	467	0.0%	0.0	17%
350	1.21	1.11	0.229	481	0.0%	0.2	21%
360	1.24	1.14	0.235	495	0.1%	0.5	24%
370	1.28	1.17	0.242	508	0.2%	1.0	28%
380	1.31	1.20	0.248	521	0.3%	1.8	31%
390	1.34	1.24	0.254	534	0.5%	2.9	34%
400	1.38	1.27	0.260	546	0.8%	4.5	37%
410	1.41	1.30	0.265	558	1.1%	6.6	40%
420	1.45	1.33	0.271	569	1.5%	9.2	43%
430	1.48	1.36	0.276	580	2.0%	12.3	46%
440	1.52	1.40	0.281	591	2.5%	15.9	48%
450	1.55	1.43	0.286	601	3.1%	19.9	51%
460	1.59	1.46	0.290	610	3.6%	24.2	53%
470	1.62	1.49	0.295	619	4.3%	28.9	56%
480	1.66	1.52	0.299	628	4.9%	34.1	58%
490	1.69	1.55	0.303	636	5.6%	39.7	60%
500	1.72	1.59	0.307	645	6.3%	45.5	62%

Table 6: **IQ 6+** - Denver, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
290	1.00	0.92	0.216	455	0.0%	0.0	0%
300	1.03	0.95	0.224	471	0.0%	0.0	3%
310	1.07	0.98	0.231	486	0.0%	0.0	7%
320	1.10	1.01	0.239	502	0.0%	0.1	10%
330	1.14	1.05	0.246	518	0.0%	0.2	14%
340	1.17	1.08	0.254	533	0.1%	0.6	17%
350	1.21	1.11	0.261	548	0.2%	1.4	21%
360	1.24	1.14	0.268	563	0.4%	2.6	24%
370	1.28	1.17	0.274	577	0.7%	4.5	27%
380	1.31	1.20	0.281	590	1.1%	7.0	30%
390	1.34	1.24	0.287	603	1.6%	10.1	33%
400	1.38	1.27	0.293	615	2.1%	14.1	35%
410	1.41	1.30	0.298	626	2.8%	18.9	38%
420	1.45	1.33	0.303	637	3.5%	24.3	40%
430	1.48	1.36	0.308	647	4.3%	30.2	42%
440	1.52	1.40	0.312	656	5.0%	36.6	44%
450	1.55	1.43	0.316	665	5.8%	43.3	46%
460	1.59	1.46	0.321	674	6.7%	50.5	48%
470	1.62	1.49	0.325	682	7.5%	58.1	50%
480	1.66	1.52	0.328	690	8.4%	66.1	52%
490	1.69	1.55	0.332	698	9.2%	74.4	53%
500	1.72	1.59	0.336	705	10.1%	82.9	55%

Table 7: **IQ 6+** - Los Angeles, -0.4%/C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
290	1.00	0.92	0.232	487	0.0%	0.0	0%
300	1.03	0.95	0.240	504	0.0%	0.0	3%
310	1.07	0.98	0.248	521	0.0%	0.0	7%
320	1.10	1.01	0.256	538	0.0%	0.0	10%
330	1.14	1.05	0.264	555	0.0%	0.0	14%
340	1.17	1.08	0.272	572	0.0%	0.0	17%
350	1.21	1.11	0.280	589	0.0%	0.2	21%
360	1.24	1.14	0.288	605	0.1%	0.7	24%
370	1.28	1.17	0.295	621	0.3%	2.0	27%
380	1.31	1.20	0.302	635	0.7%	4.4	30%
390	1.34	1.24	0.309	649	1.1%	7.6	33%
400	1.38	1.27	0.315	662	1.7%	11.9	36%
410	1.41	1.30	0.320	674	2.3%	17.0	38%
420	1.45	1.33	0.326	685	3.0%	22.5	41%
430	1.48	1.36	0.331	696	3.8%	28.5	43%
440	1.52	1.40	0.336	707	4.5%	35.1	45%
450	1.55	1.43	0.341	717	5.3%	42.3	47%
460	1.59	1.46	0.345	726	6.2%	50.2	49%
470	1.62	1.49	0.349	734	7.1%	58.8	51%
480	1.66	1.52	0.353	742	8.0%	67.7	52%
490	1.69	1.55	0.357	750	8.9%	76.9	54%
500	1.72	1.59	0.360	758	9.8%	86.4	56%

Table 8: **IQ 6+** - Phoenix, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
290	1.00	0.92	0.253	531	0.0%	0.0	0%
300	1.03	0.95	0.261	549	0.0%	0.0	3%
310	1.07	0.98	0.270	568	0.0%	0.0	7%
320	1.10	1.01	0.279	586	0.0%	0.0	10%
330	1.14	1.05	0.288	605	0.0%	0.0	14%
340	1.17	1.08	0.296	623	0.0%	0.0	17%
350	1.21	1.11	0.305	642	0.0%	0.1	21%
360	1.24	1.14	0.314	660	0.0%	0.3	24%
370	1.28	1.17	0.322	678	0.1%	1.0	28%
380	1.31	1.20	0.330	695	0.3%	2.2	31%
390	1.34	1.24	0.338	711	0.6%	4.3	34%
400	1.38	1.27	0.345	726	1.0%	7.7	37%
410	1.41	1.30	0.352	740	1.6%	12.5	39%
420	1.45	1.33	0.358	753	2.3%	18.5	42%
430	1.48	1.36	0.363	764	3.1%	25.5	44%
440	1.52	1.40	0.369	775	3.9%	33.3	46%
450	1.55	1.43	0.373	785	4.8%	41.9	48%
460	1.59	1.46	0.378	794	5.8%	51.0	50%
470	1.62	1.49	0.382	803	6.7%	60.5	51%
480	1.66	1.52	0.386	812	7.6%	70.5	53%
490	1.69	1.55	0.390	820	8.6%	80.9	54%
500	1.72	1.59	0.394	828	9.5%	91.7	56%

IQ 7 Simulation Results

The following tables indicate example simulated single-module year-one inverter capacity factor, clipping and energy yield for various DC:AC ratios on the IQ 7 Microinverter in various US locations, using a -0.4%/C simple efficiency model. The IQ 7 Microinverter has a peak output power rating of 250 VA. In this model, the module orientation is fixed at 180° azimuth, 25° tilt, and L_{total} at 5.6%. Many real-world PV systems do not have ideal true south orientations of 180° azimuth and ideal tilt angles, so the impact of clipping will be less than shown in the tables below.

Table 9: **IQ 7** - Newark, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
250	1.00	0.92	0.163	342	0.0%	0.0	0%
260	1.04	0.96	0.169	356	0.0%	0.0	4%
270	1.08	0.99	0.176	369	0.0%	0.0	8%
280	1.12	1.03	0.182	383	0.0%	0.0	12%
290	1.16	1.07	0.189	397	0.0%	0.0	16%
300	1.20	1.10	0.195	411	0.0%	0.1	20%
310	1.24	1.14	0.202	424	0.1%	0.4	24%
320	1.28	1.18	0.208	438	0.2%	0.8	28%
330	1.32	1.21	0.214	451	0.3%	1.6	32%
340	1.36	1.25	0.220	463	0.6%	2.9	36%
350	1.40	1.29	0.226	476	0.9%	4.6	39%
360	1.44	1.32	0.232	487	1.3%	6.9	43%
370	1.48	1.36	0.237	498	1.8%	9.8	46%
380	1.52	1.40	0.242	508	2.4%	13.2	49%
390	1.56	1.43	0.247	518	3.0%	17.1	52%
400	1.60	1.47	0.251	528	3.7%	21.4	54%
410	1.64	1.51	0.255	537	4.4%	26.2	57%
420	1.68	1.54	0.259	545	5.2%	31.5	60%

Table 10: **IQ 7** - Denver (Golden), -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
250	1.00	0.92	0.186	391	0.0%	0.0	0%
260	1.04	0.96	0.193	407	0.0%	0.0	4%
270	1.08	0.99	0.201	422	0.0%	0.0	8%
280	1.12	1.03	0.208	438	0.0%	0.1	12%
290	1.16	1.07	0.216	454	0.1%	0.3	16%
300	1.20	1.10	0.223	469	0.2%	0.9	20%
310	1.24	1.14	0.230	483	0.4%	2.0	24%
320	1.28	1.18	0.237	497	0.7%	3.7	27%
330	1.32	1.21	0.243	511	1.1%	6.2	31%
340	1.36	1.25	0.249	523	1.7%	9.5	34%
350	1.40	1.29	0.254	535	2.4%	13.7	37%
360	1.44	1.32	0.259	545	3.2%	18.8	40%
370	1.48	1.36	0.264	555	4.0%	24.5	42%
380	1.52	1.40	0.269	565	4.9%	30.6	45%
390	1.56	1.43	0.273	574	5.8%	37.3	47%
400	1.60	1.47	0.277	583	6.7%	44.4	49%
410	1.64	1.51	0.281	591	7.7%	52.0	51%
420	1.68	1.54	0.285	599	8.7%	60.0	53%

Table 11: **IQ 7** - Los Angeles, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
250	1.00	0.92	0.199	419	0.0%	0.0	0%
260	1.04	0.96	0.207	435	0.0%	0.0	4%
270	1.08	0.99	0.215	452	0.0%	0.0	8%
280	1.12	1.03	0.223	469	0.0%	0.0	12%
290	1.16	1.07	0.231	486	0.0%	0.0	16%
300	1.20	1.10	0.239	503	0.0%	0.1	20%
310	1.24	1.14	0.247	519	0.1%	0.5	24%
320	1.28	1.18	0.254	535	0.3%	1.7	28%
330	1.32	1.21	0.261	549	0.7%	4.0	31%
340	1.36	1.25	0.268	563	1.2%	7.4	35%
350	1.40	1.29	0.274	575	1.9%	12.0	37%
360	1.44	1.32	0.279	587	2.7%	17.2	40%
370	1.48	1.36	0.284	598	3.5%	22.9	43%
380	1.52	1.40	0.289	609	4.4%	29.3	45%
390	1.56	1.43	0.294	618	5.3%	36.4	48%
400	1.60	1.47	0.298	627	6.3%	44.3	50%
410	1.64	1.51	0.302	636	7.3%	52.9	52%
420	1.68	1.54	0.306	644	8.3%	61.8	54%

Table 12: **IQ 7** - Phoenix, -0.4%/°C simple efficiency model, 5.6% L_{total}, 180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
250	1.00	0.92	0.217	456	0.0%	0.0	0%
260	1.04	0.96	0.226	475	0.0%	0.0	4%
270	1.08	0.99	0.235	493	0.0%	0.0	8%
280	1.12	1.03	0.243	511	0.0%	0.0	12%
290	1.16	1.07	0.252	530	0.0%	0.0	16%
300	1.20	1.10	0.261	548	0.0%	0.1	20%
310	1.24	1.14	0.269	566	0.0%	0.2	24%
320	1.28	1.18	0.278	584	0.1%	0.8	28%
330	1.32	1.21	0.286	601	0.3%	2.0	32%
340	1.36	1.25	0.294	617	0.7%	4.3	35%
350	1.40	1.29	0.300	632	1.2%	8.2	38%
360	1.44	1.32	0.307	645	2.0%	13.6	41%
370	1.48	1.36	0.312	656	2.8%	20.1	44%
380	1.52	1.40	0.317	667	3.8%	27.7	46%
390	1.56	1.43	0.322	677	4.8%	36.1	48%
400	1.60	1.47	0.327	687	5.9%	45.2	50%
410	1.64	1.51	0.331	695	6.9%	54.7	52%
420	1.68	1.54	0.335	704	8.0%	64.7	54%

IQ 7+ Simulation Results

The following tables indicate example simulated single-module year-one inverter capacity factor, clipping and energy yield for various DC:AC ratios on the IQ 7+ Microinverter in various US locations, using a -0.4%/C simple efficiency model. The IQ 7+ Microinverter has a peak output power rating of 295 VA. In this model, the module orientation is fixed at 180° azimuth, 25° tilt, and L_{total} at 5.6%. Many real-world PV systems do not have ideal true south orientations of 180° azimuth and ideal tilt angles, so impact of clipping will be less than shown in the tables below.

Table 13: **IQ 7+** - Newark, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
295	1.00	0.92	0.192	404	0.0%	0.0	0%
305	1.03	0.95	0.199	418	0.0%	0.0	3%
315	1.07	0.98	0.206	432	0.0%	0.0	7%
325	1.10	1.01	0.212	446	0.0%	0.0	10%
335	1.14	1.04	0.219	460	0.0%	0.0	14%
345	1.17	1.08	0.225	473	0.0%	0.0	17%
355	1.20	1.11	0.232	487	0.0%	0.1	20%
365	1.24	1.14	0.238	501	0.1%	0.4	24%
375	1.27	1.17	0.244	514	0.1%	0.8	27%
385	1.31	1.20	0.251	527	0.3%	1.5	30%
395	1.34	1.23	0.257	540	0.4%	2.4	34%
405	1.37	1.26	0.263	552	0.7%	3.8	37%
415	1.41	1.29	0.268	564	0.9%	5.6	40%
425	1.44	1.32	0.274	576	1.3%	7.9	42%
435	1.47	1.36	0.279	587	1.7%	10.7	45%
445	1.51	1.39	0.284	597	2.2%	14.0	48%
455	1.54	1.42	0.289	607	2.7%	17.7	50%
465	1.58	1.45	0.293	617	3.2%	21.8	53%
475	1.61	1.48	0.298	626	3.8%	26.1	55%
485	1.64	1.51	0.302	635	4.4%	30.9	57%
495	1.68	1.54	0.306	644	5.1%	36.2	59%
505	1.71	1.57	0.310	652	5.7%	41.7	61%

Table 14: **IQ 7+** - Denver, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
295	1.00	0.92	0.220	462	0.0%	0.0	0%
305	1.03	0.95	0.227	478	0.0%	0.0	3%
315	1.07	0.98	0.235	493	0.0%	0.0	7%
325	1.10	1.01	0.242	509	0.0%	0.0	10%
335	1.14	1.04	0.250	525	0.0%	0.2	14%
345	1.17	1.08	0.257	540	0.1%	0.5	17%
355	1.20	1.11	0.264	555	0.2%	1.1	20%
365	1.24	1.14	0.271	570	0.4%	2.1	23%
375	1.27	1.17	0.278	584	0.6%	3.7	26%
385	1.31	1.20	0.284	597	0.9%	5.9	29%
395	1.34	1.23	0.290	610	1.3%	8.8	32%
405	1.37	1.26	0.296	622	1.9%	12.4	35%
415	1.41	1.29	0.301	634	2.4%	16.7	37%
425	1.44	1.32	0.306	644	3.1%	21.7	39%
435	1.47	1.36	0.311	654	3.8%	27.3	42%
445	1.51	1.39	0.316	664	4.5%	33.3	44%
455	1.54	1.42	0.320	673	5.3%	39.7	46%
465	1.58	1.45	0.325	682	6.1%	46.4	48%
475	1.61	1.48	0.329	691	6.9%	53.7	50%
485	1.64	1.51	0.332	699	7.7%	61.3	51%
495	1.68	1.54	0.336	707	8.5%	69.2	53%
505	1.71	1.57	0.340	714	9.3%	77.3	55%

Table 15: **IQ 7+** - Los Angeles, -0.4%/C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
295	1.00	0.92	0.235	495	0.0%	0.0	0%
305	1.03	0.95	0.243	512	0.0%	0.0	3%
315	1.07	0.98	0.251	528	0.0%	0.0	7%
325	1.10	1.01	0.259	545	0.0%	0.0	10%
335	1.14	1.04	0.267	562	0.0%	0.0	14%
345	1.17	1.08	0.275	579	0.0%	0.0	17%
355	1.20	1.11	0.283	596	0.0%	0.1	20%
365	1.24	1.14	0.291	612	0.1%	0.5	24%
375	1.27	1.17	0.299	628	0.2%	1.4	27%
385	1.31	1.20	0.306	643	0.5%	3.4	30%
395	1.34	1.23	0.312	657	0.9%	6.2	33%
405	1.37	1.26	0.319	670	1.4%	10.0	35%
415	1.41	1.29	0.324	682	2.0%	14.7	38%
425	1.44	1.32	0.330	693	2.6%	19.9	40%
435	1.47	1.36	0.335	704	3.3%	25.5	42%
445	1.51	1.39	0.340	715	4.0%	31.6	45%
455	1.54	1.42	0.345	725	4.8%	38.4	47%
465	1.58	1.45	0.349	735	5.6%	45.7	48%
475	1.61	1.48	0.354	743	6.4%	53.7	50%
485	1.64	1.51	0.358	752	7.3%	62.3	52%
495	1.68	1.54	0.361	760	8.1%	71.1	54%
505	1.71	1.57	0.365	767	9.0%	80.2	55%

Table 16: **IQ 7+** - Phoenix, -0.4%/°C simple efficiency model, 5.6% L_{total} ,180° azimuth, 25° tilt.

Module STC (Wdc)	DC:AC Ratio	Nominal DC:AC Ratio	Capacity factor	Annual energy (kWh)	Year one Inverter clipping loss (%)	Year one Inverter clipping loss (kWh)	Energy yield increase over 1.0 DC:AC ratio (%)
295	1.00	0.92	0.257	539	0.0%	0.0	0%
305	1.03	0.95	0.265	558	0.0%	0.0	3%
315	1.07	0.98	0.274	576	0.0%	0.0	7%
325	1.10	1.01	0.283	594	0.0%	0.0	10%
335	1.14	1.04	0.291	613	0.0%	0.0	14%
345	1.17	1.08	0.300	631	0.0%	0.0	17%
355	1.20	1.11	0.309	649	0.0%	0.1	20%
365	1.24	1.14	0.317	667	0.0%	0.2	24%
375	1.27	1.17	0.326	685	0.1%	0.7	27%
385	1.31	1.20	0.334	702	0.2%	1.6	30%
395	1.34	1.23	0.342	719	0.4%	3.3	33%
405	1.37	1.26	0.349	734	0.8%	6.1	36%
415	1.41	1.29	0.356	748	1.3%	10.2	39%
425	1.44	1.32	0.362	761	1.9%	15.6	41%
435	1.47	1.36	0.368	773	2.6%	21.9	43%
445	1.51	1.39	0.373	784	3.4%	29.2	45%
455	1.54	1.42	0.378	794	4.3%	37.2	47%
465	1.58	1.45	0.382	804	5.1%	45.8	49%
475	1.61	1.48	0.387	813	6.0%	54.9	51%
485	1.64	1.51	0.391	822	6.9%	64.4	52%
495	1.68	1.54	0.395	830	7.8%	74.3	54%
505	1.71	1.57	0.399	838	8.7%	84.6	55%

Conclusion

The primary purpose of this paper is to provide a technical framework for discussion. Some common configurations of Enphase Inverters were simulated in NREL SAM to illustrate how various performance metrics change by varying DC:AC ratios.

PV modules seldom produce power at their test condition power rating. This leads installers to pair PV modules with power ratings higher than the inverter power rating. In many locations, high DC:AC ratios may not result in significant clipping losses. However, further increasing the DC:AC ratio will increase the inverter capacity factor which may increase the value of the system.