



White Paper

Solar Clipping Recapture - Overview



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0.1

Introduction

Generally, under a Power Purchase Agreement (PPA), the power vendor seeks to supply as much energy as possible to the point of interconnection while respecting an upper power limit. To be completely clear about what this means, let us review a couple of basic concepts whose difference is important to know: energy and power.

Energy is generated when a power is maintained for a certain time. It is essential to note the difference between the units of these two concepts: Energy uses Wh (watt-hour) or its multiples kWh (kilowatt-hour), MWh (megawatt-hour), or GWh (gigawatt-hour); and Power uses W (watt) or its multiples kW (kilowatt), MW (megawatt), or GW (gigawatt). The “h” in Wh is paramount.

Let us analyze a couple of examples to see the difference between energy and power. If we have a Diesel Power Generator of nominal power of 500 kW, we can have different energy productions depending on how long the generator is running. (For the sake of simplicity, we will ignore any system losses and consider an ideal generator.)

Example 1: If the Diesel Power Generator of 500 kW operates for 3 hours, the energy generated will be 1,500 kWh:

$$\text{Energy Generated} = \text{Power} * \text{Time Period} = 500 \text{ kW} * 3 \text{ hours} = 1,500 \text{ kWh}$$

Example 2: If the Diesel Power Generator of 500 kW operates for 6 hours, the energy generated will be 3,000 kWh:

$$\text{Energy Generated} = \text{Power} * \text{Time Period} = 500 \text{ kW} * 6 \text{ hours} = 3,000 \text{ kWh}$$

As you can see from the examples above, the same Diesel Power Generator of 500 kW of power yielded different energy productions (kWh) depending on how long the generator is running. Figures 1 and 2 show these examples in graphic form. Note that in these graphs the area under the power curve is the energy generated during that time (the area marked with kWh). For reference, energy is defined mathematically as the integral of the power function over time.

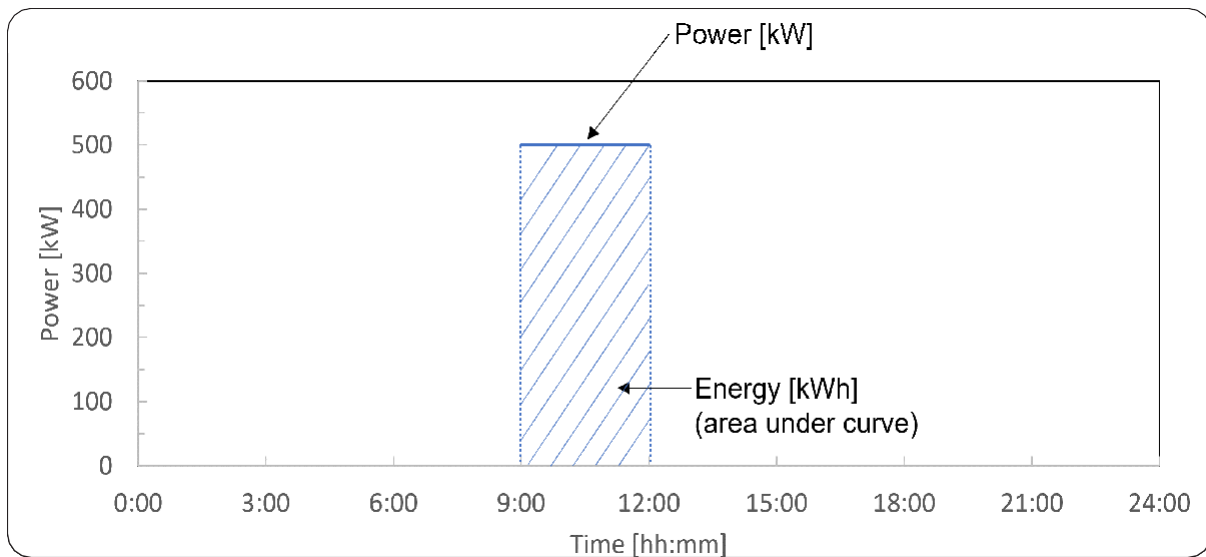


FIGURE 1 GRAPHIC REPRESENTATION OF EXAMPLE # 1. (SOURCE OF IMAGE: OWN ELABORATION.)

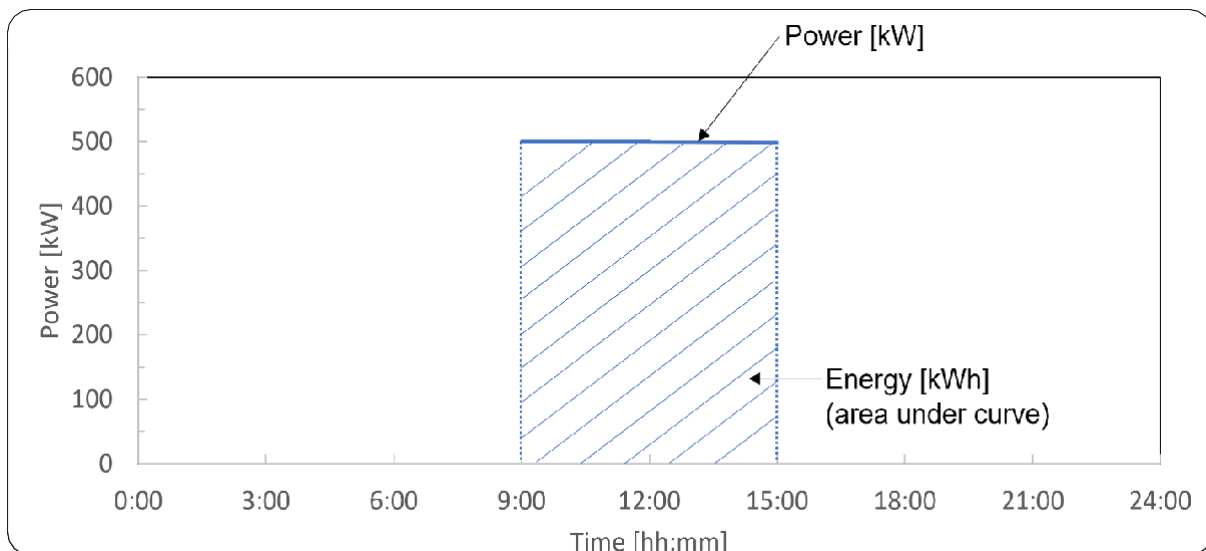


FIGURE 2 GRAPHIC REPRESENTATION OF EXAMPLE # 2. (SOURCE OF IMAGE: OWN ELABORATION.)

The energy calculation for a diesel generator is simple because the power output remains constant over time. This is due to the fact that the supply of the primary energy resource (diesel, in this case) is constant (barring maintenance or failure). This, however, does not happen in other power generation technologies, such as renewables, in which the primary energy resource is intermittent. In this article, we will be considering a Solar Photovoltaic (PV) Generator as a reference. In this type of generator, the primary energy resource (sun's electromagnetic radiation, aka sunlight) is not constant throughout the day.

In Figure 3, we can see an ideal (no clouds) generation profile of a Solar PV Generator. It can be seen that the power output is not constant because the sunlight is not as strong in the morning or afternoon as it is at noon, and therefore the calculation is no longer as simple as that of the diesel generator.

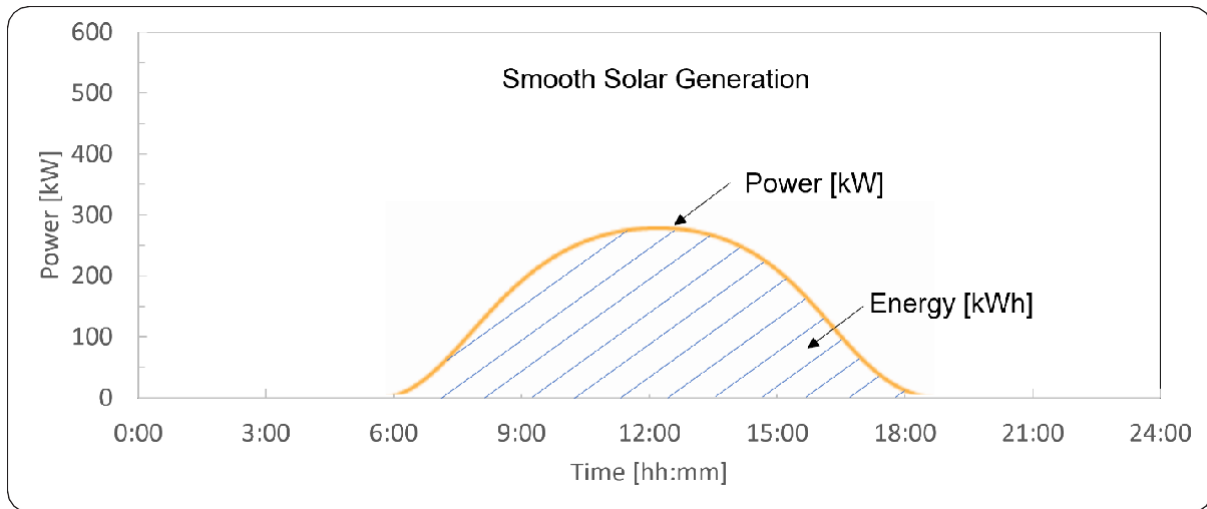


FIGURE 3 POWER GENERATION PROFILE FOR A SOLAR PV GENERATOR IN AN IDEAL SUNNY DAY. (SOURCE OF IMAGE: [HTTPS://CARBONTRACK.COM.AU/BLOG/SOLAR-EXPORT-CONTROL-QUICK-GUIDE/](https://carbontrack.com.au/blog/solar-export-control-quick-guide/))

Meanwhile, Figure 4 presents a more realistic generation profile of a Solar PV Generator. Although the generation profile of a photovoltaic solar system is not as constant as the profile of a diesel generator, **the fact that energy is the area under the power generation curve is still valid.**

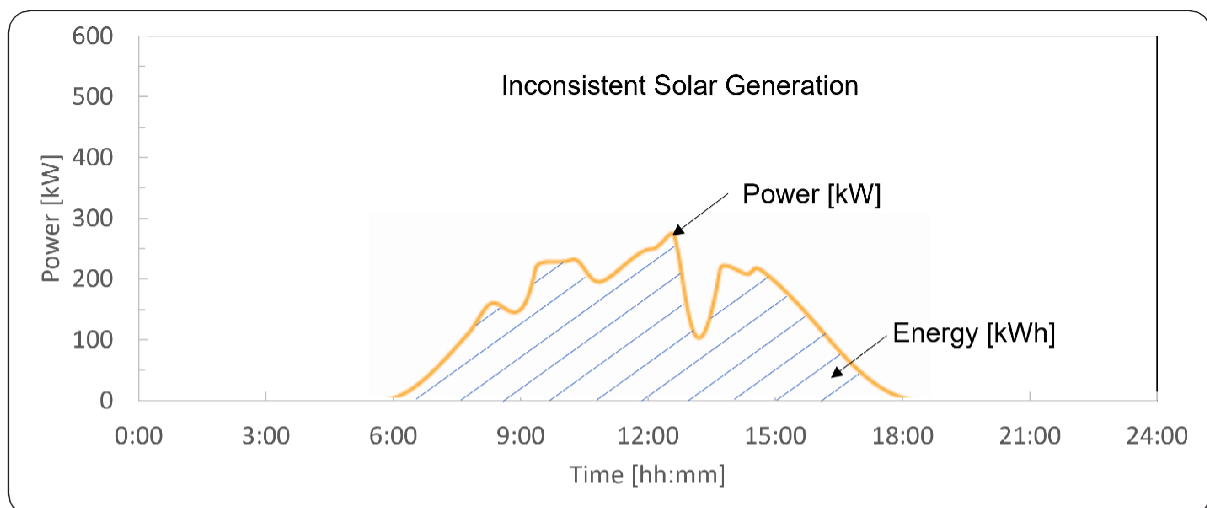


FIGURE 4 THE ENERGY GENERATED BY A SOLAR PV GENERATOR IN A MORE REALISTIC SCENARIO IS THE AREA MARKED IN BLUE. (SOURCE OF IMAGE: [HTTPS://CARBONTRACK.COM.AU/BLOG/SOLAR-EXPORT-CONTROL-QUICK-GUIDE/](https://carbontrack.com.au/blog/solar-export-control-quick-guide/))

Now that we have highlighted the important difference between energy and power, we'll proceed to discussing Inverter Load Ratios (ILR) and Clipped Energy in Solar PV Generators.

0.2

Inverter Load Ratio (ILR) and Clipped Energy in Solar PV Generators

As we mentioned in the introduction, the power vendor of a PPA wants to maximize the energy sold under a power cap. To keep consistent with our previous examples, we will continue working with a 500 kW *power size*.

For the rest of this article, we will assume that we are the selling party of a PPA of 500 kW.

If we want to maximize the energy generated under this power limit, the ideal scenario is to have a constant generation source like the diesel generator mentioned in our previous examples and put it to work throughout the day. In reality this is not 100% possible because of scheduled maintenance and possible failures. However, for the sake of our discussion, the ideal power generation profile would look as shown in Figure 5.

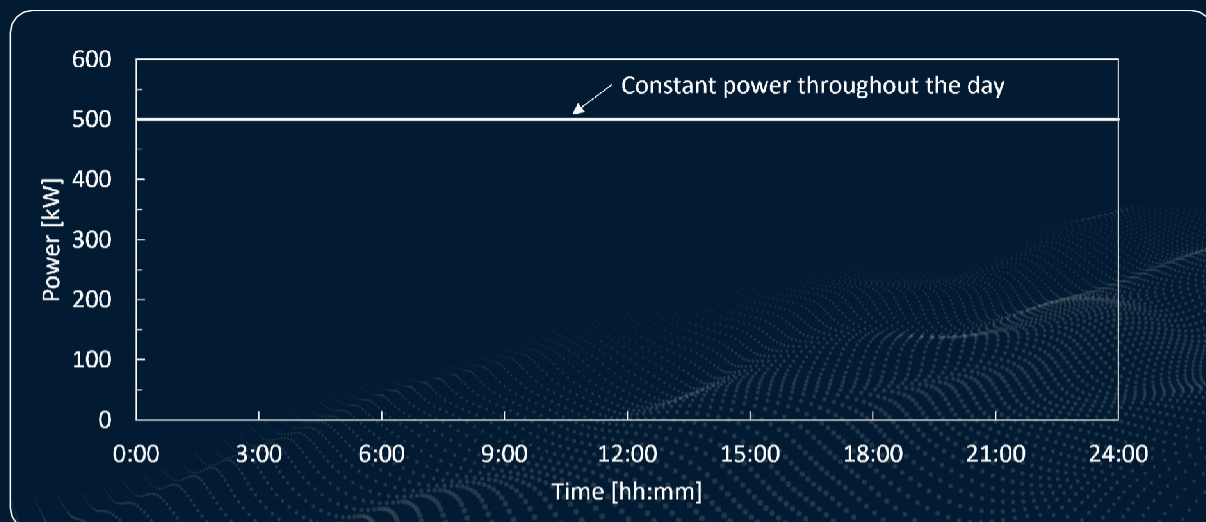


FIGURE 5 IDEAL POWER GENERATION PROFILE FOR A DIESEL POWER GENERATOR IN 24 HOURS. (SOURCE OF IMAGE: OWN ELABORATION.)

This constant power over 24 hours would not be possible with a 500 kW photovoltaic generator due to the variability of its primary energy resource (sunlight) during the day and also throughout the year. In fact, the nominal 500 kW power would only be reached occasionally during the year when ideal weather conditions presented themselves (see Figure 6). The difference in energy generation between these two generation profiles (Figure 5 and Figure 6) can be seen in Figure 7.

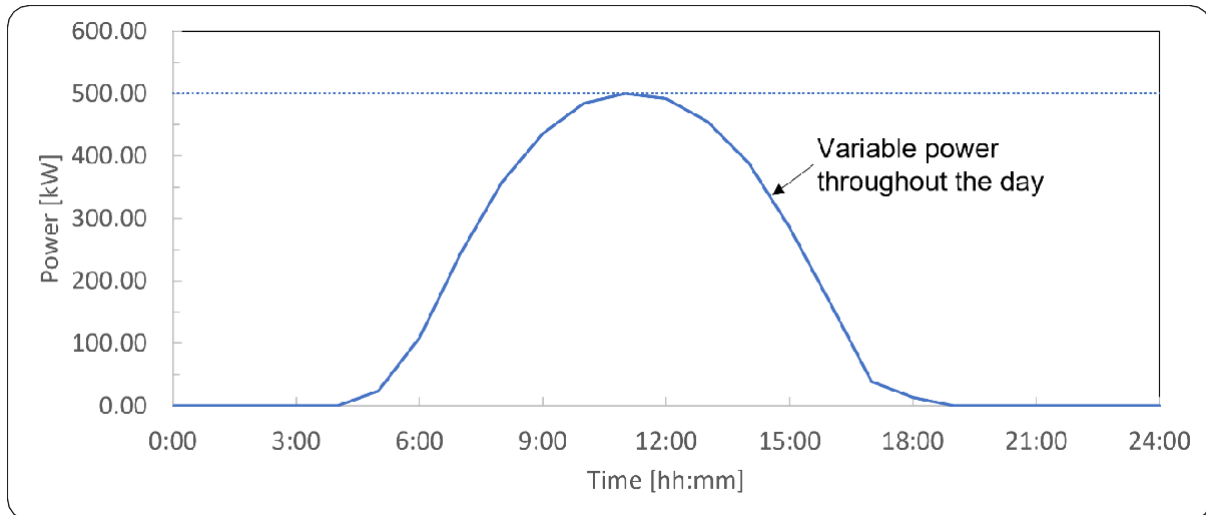


FIGURE 6 POWER GENERATION PROFILE FOR A 500 kW SOLAR PV GENERATOR IN 24 HOURS (SUNNY AND NO-CLOUDY CONDITIONS, ILR 1.25). (SOURCE OF IMAGE: OWN ELABORATION.)

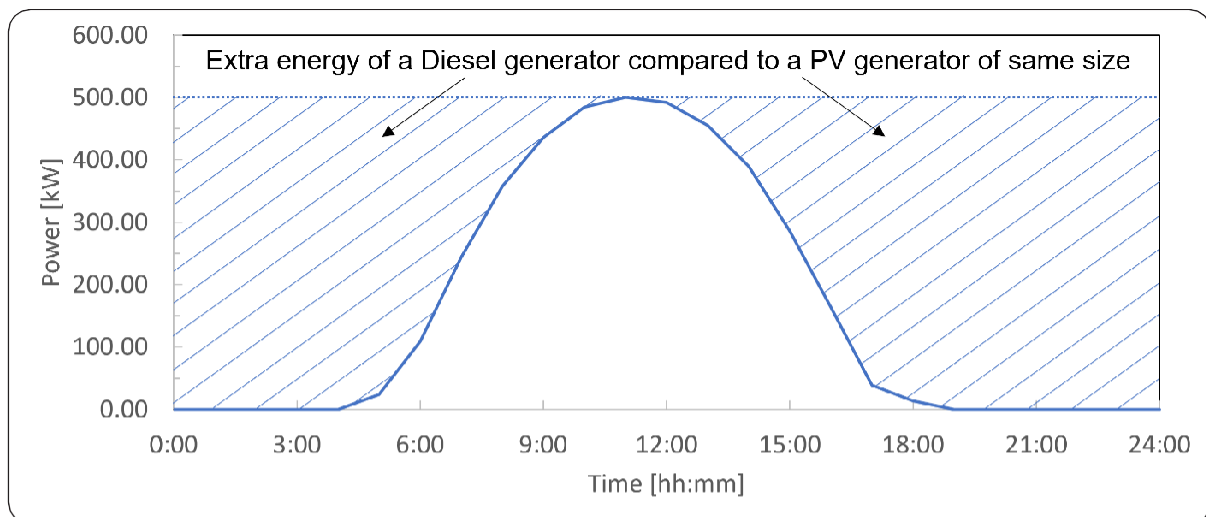


FIGURE 7 EXTRA ENERGY GENERATED BY AN IDEAL DIESEL GENERATOR COMPARED TO A SOLAR PV GENERATOR OF SAME SIZE IN SUNNY, NO-CLOUDY CONDITIONS. (SOURCE OF IMAGE: OWN ELABORATION.)

To try to “solve” this variability problem for the Solar PV Generator and maximize the energy that we could sell, always respecting the power limit, one thing we could do is increase the number of photovoltaic modules (DC nominal power capacity, kWp) connected to our solar inverters (AC nominal power capacity, kW). This is called *increasing the Inverter Load Ratio* (ILR) of our Solar PV Generator, which is the ratio between these two nominal power capacities.

Generally, solar PV generators use an ILR greater than one (inverters’ power capacity less than PV modules’ power capacity) because the nominal power of photovoltaic modules is associated with ideal laboratory conditions known as Standard Test Conditions (STC). For this reason, when PV modules are deployed in the field where ambient conditions are different from those of a laboratory, they provide less power than that specified

under these STCs. It makes more sense from an economic point of view to size the inverters’ power capacity to the actual field generation capacity of the PV modules and not to the ideal potential capacity under laboratory conditions, because otherwise the inverters would be oversized and this oversize costs us money. (Determining the ideal ILR for a solar PV generator depends on the location of the project and is beyond the scope of this article.)

Figure 6 shows the ideal generation profile for one day of a Solar PV Generator with an ILR of 1.25 (625 kWp in PV modules and 500 kW in solar inverters). And Figure 8 shows the ideal generation profile for one day of a generator with an ILR of 2 (1,000 kWp in PV modules and 500 kW in solar inverters). Notice that the 500 kW in solar inverters is the same for our two scenarios to comply with the power limit agreed to in the PPA.

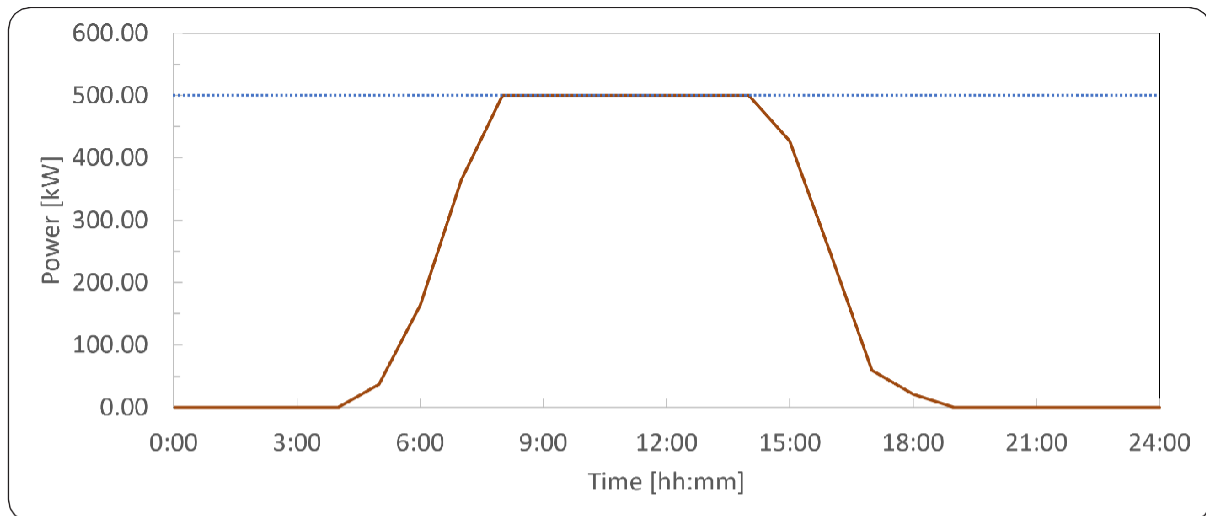


FIGURE 8 POWER GENERATION PROFILE FOR A SOLAR PV GENERATOR IN 24 HOURS (SUNNY AND NO-CLOUDY CONDITIONS, ILR 2.00). (SOURCE OF IMAGE: OWN ELABORATION.)

If we combine Figures 6 and 8, we get Figure 9. This figure shows the “gain” of energy that we would have if we increased the ILR in our system from 1.25 to 2.00.

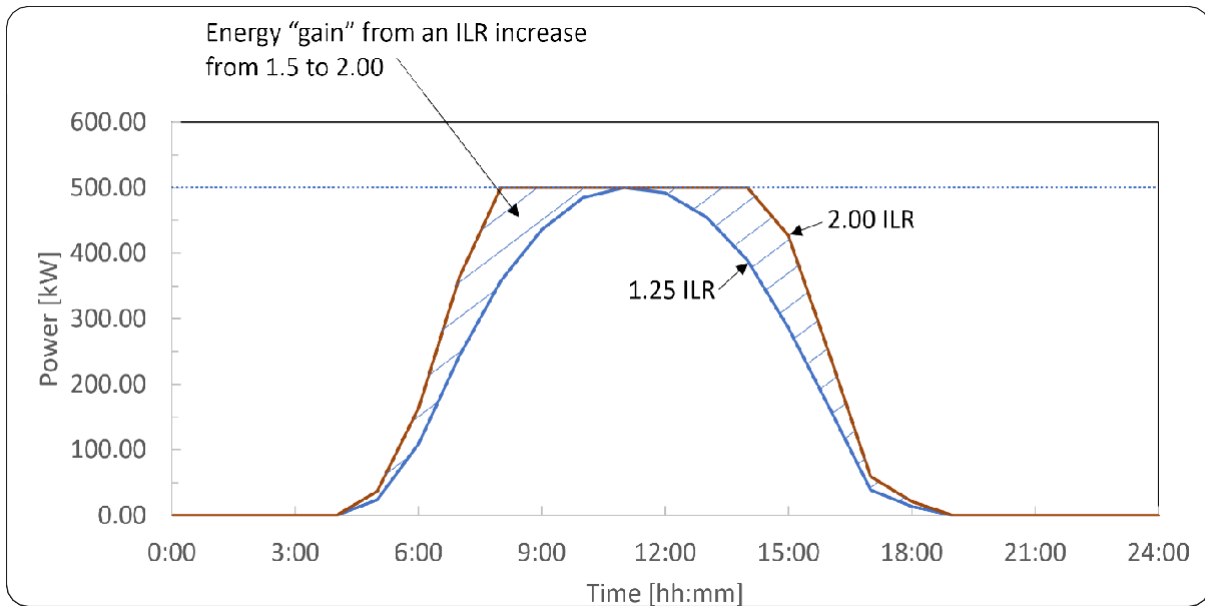


FIGURE 9 ENERGY “GAIN” FROM AN ILR INCREASE FROM 1.25 TO 2.00 FOR A 500 KWAC SOLAR PV GENERATOR. (SOURCE OF IMAGE: OWN ELABORATION.)

Looking at Figure 9, the first question that comes to mind is: Why would we not continue to increase the ILR until the photovoltaic generation curve equals that of a diesel generator at least during the hours that the solar irradiance allows it, as shown in Figure 10? The answer is: because of Clipped Energy.

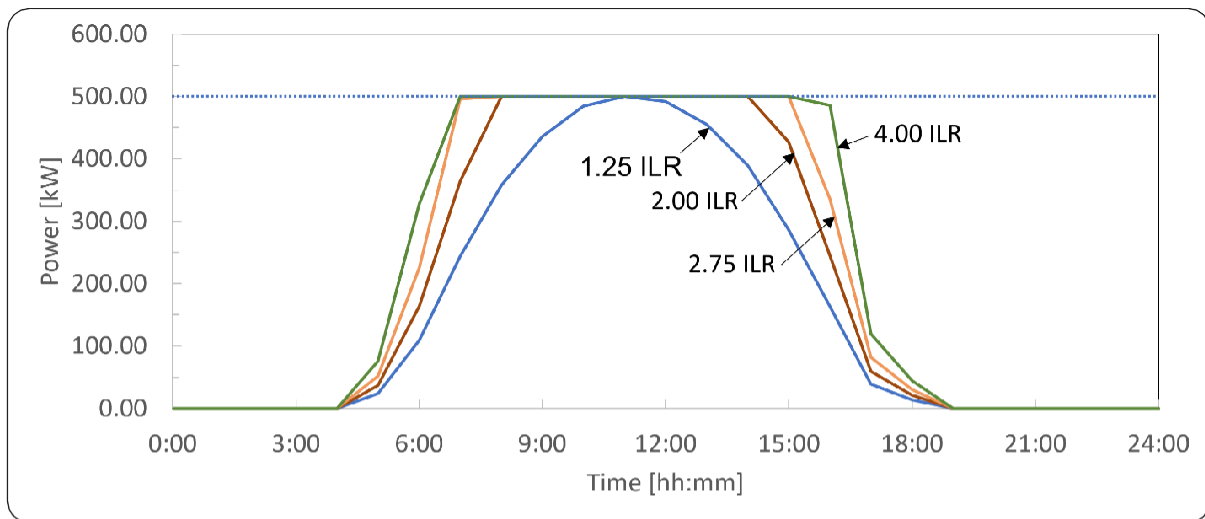


FIGURE 10 POWER GENERATION PROFILE FOR A SOLAR PV GENERATOR WITH DIFFERENT ILRS. (SOURCE OF IMAGE: OWN ELABORATION.)

The “gain” of energy discussed in Figure 9 comes with an associated tradeoff which is typically known as Clipped Energy. This energy is the energy not harnessed, and therefore considered lost, because the solar inverters reach their generation limit and they are forced to move the solar PV array’s operating point away from its Maximum Power Point (MPP). How this happens is beyond the scope of this article but the important element here is that there is potential energy or untapped energy that could be harnessed. Please refer to Figures 11 and 12.

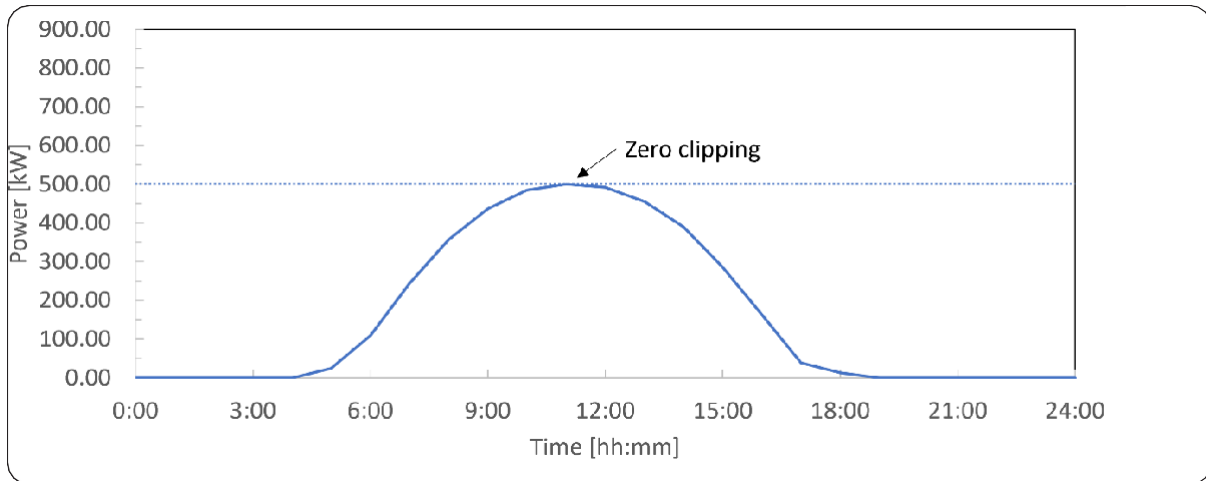


FIGURE 11 EXAMPLE OF ZERO CLIPPED ENERGY FOR A SOLAR PV GENERATOR WITH 1.25 ILR. (SOURCE OF IMAGE: OWN ELABORATION.)

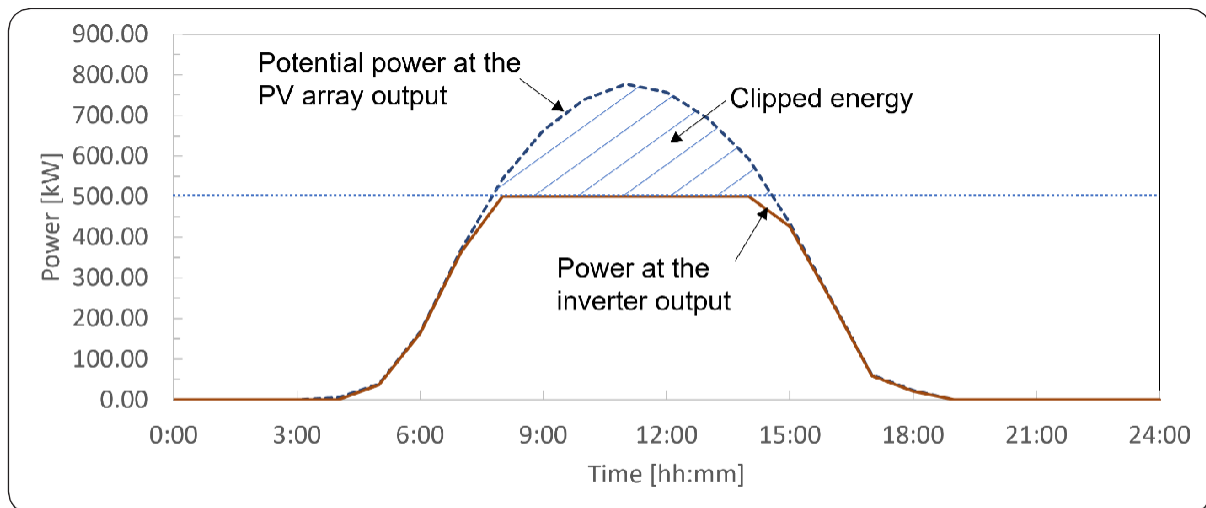


FIGURE 12 GRAPH REPRESENTATION OF CLIPPED ENERGY FOR A SOLAR PV GENERATOR WITH A 2.00 ILR. (SOURCE OF IMAGE: OWN ELABORATION.)

Within a certain range, it makes sense to keep increasing the ILR without much consideration of clipping losses, especially if the Levelized Cost of Electricity (LCOE) is less than the price at which energy is being sold. However, there comes a point where it does not make financial sense to continue investing in more capital cost to keep introducing PV modules: when the benefits of selling the gained energy from an increase in ILR are less than the costs associated with this ILR increase. In other words, and in a more graphic way: when the benefits originated by the green area shown in Figure 13 are inferior to the costs associated to both the red and green areas shown in the same figure.

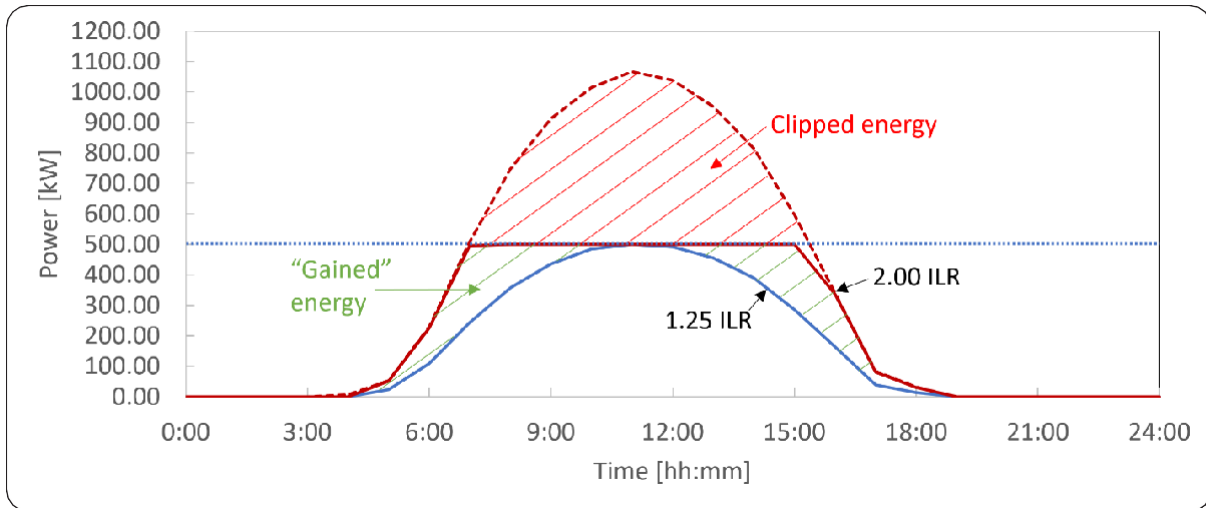


FIGURE 13 TRADE OFF BETWEEN CLIPPED AND GAINED ENERGY FOR AN ILR INCREASE. (SOURCE OF IMAGE: OWN ELABORATION.)



0.3

Clipping Recapture or DC Coupling

As discussed in the previous section, clipped energy is potential energy that can be harnessed. This is where our protagonist comes in: Clipping Recapture, also known as DC Coupling.

Clipping Recapture is the storing of clipped energy in an energy storage system like a Battery Energy Storage System (BESS) and using this stored energy at a more convenient time (when you have a better sale price, for example). Because the energy storage happens on the DC voltage side of the Solar PV Generator, it is also known as DC coupling. Please refer to Figure 14.

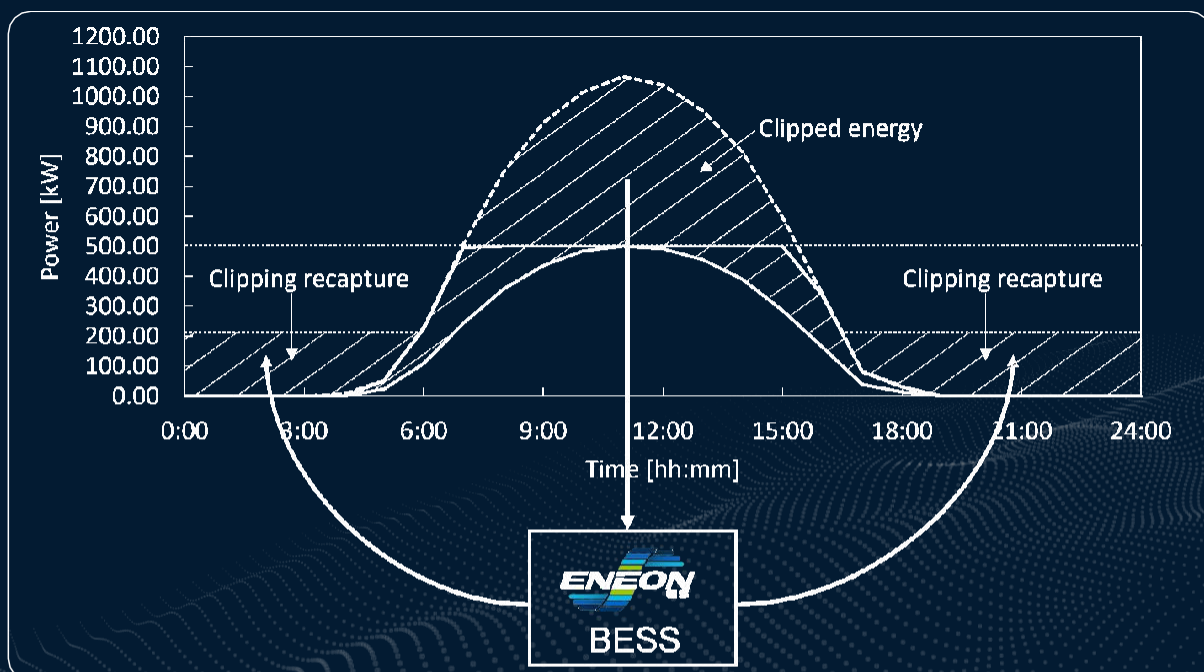


FIGURE 14 SOLAR CLIPPING RECAPTURE USING A BATTERY ENERGY STORAGE SYSTEM (BESS) FROM ENEON-ES. (SOURCE OF IMAGE: OWN ELABORATION ADAPTED FROM FLORES, H.F.V., FURUBAYASHI, T. & NAKATA, T. (2016).)

By implementing clipping recapture, we gain the best of two worlds: (1) we create a generation curve during the day similar to the constant power generation curve of a diesel generator, and (2) we harness the clipped energy that would otherwise be wasted.

Although the concept of clipping recapture is simple, implementing it in real projects can be challenging.

Successful projects begin with solar system analysis and clipping recapture efficiency modelling. This initial modelling gives you the tools you need to make informed decisions regarding equipment selection and battery sizing, and allows you to “right size” your BESS and ensure that you do not allocate capital to battery capacity that you do not need.

Eneon’s experienced application team is ready to support you with:

1. DC Clipping recapture analysis and modelling
2. Equipment selection
3. Interconnect support (?)
4. System design
5. Turnkey System integration, installation, testing, and commissioning

Please reach out today to book your introductory meeting where experienced Eneon staff can walk you through efficiency modelling and how it can work for you.





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